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THE NEUROSCIENCE OF SYNTAX, SEMANTICS AND QUALIA

BRAIN AND MIND: DESCARTES AND KANT.

MAX R. BENNETT
(with illustrations by
GILLIAN BENNETT)

Descartes (Figure1) first posed the dualistic problem of the relationship between the brain, treated as an object for physical study, and consciousness. Kant (Figure 2) analyzed this problem further by distinguishing between sensory information, such as temperature and vision, that we receive through the excitation of different classes of sensory receptors and those activities that categorize these experiences as belonging to, for example, substances or to causal relations.To the first of these he gave the name Sensibilities and to the latter Categories of Understanding. Kant thought that the gathering of Sensibilities was most likely carried out by physical processes whereas the mind uses its Categories of Understanding to construct our awareness and comprehension of the physical world from the Sensibilities. The reception of sensory information and its early processing by the nervous system is generally agreed to be a physical procedure. This is thought to obey procedures that have a clear syntactical structure. Such a structure involves a systematic statement of the rules governing the formulas of a logical system, like those that determine the arrangement of words and phrases in sentences, or the organization of computer programs. On the other hand, our comprehension of the physical world requires understanding the meaning of signs and symbols, including things like sentences and words; this is the problem of semantics. At perhaps an even more complex level, there are also feelings and sensations that accompany our awareness of the world; the set of these that are associated with a particular object are called qualia.

The question arises as to whether the procedures of semantics or the development of qualia are clearly such that they are carried out by physical means, like those generally agreed to be responsible for the syntactical mechanisms in the nervous system involved in the generation of sensations. This essay is concerned then with the problem of how might syntax, semantics and qualia arise in the nervous system.

NEURONAL MECHANISMS FOR SYNTAX: ALAN TURING AND DAVID MARR.

David Marr suggested that the syntactical structure of the information processing that is carried out by the Sensibilities can be divided into three levels. These are illustrated by means of the problem of what is called global stereopsis. In this the visual system seeks to arrive at a three-dimensional reconstruction of an object that is being viewed by the retinas of both eyes. There are three levels at which this information processing task must be analyzed, according to Marr. The first of these involves computational theory: in this we seek a definition of the information processing problem whose solution is the goal of the computation; in this case the problem of global stereopsis, which involves characterization of the abstract properties of the computation to be carried out. Surprisingly, this is in general by far the most complex aspect of trying to seek a solution to an information processing task.In the case of global stereopsis it involves identifying the properties of the visible world that constrain the computational problem. For example, one of these might be that surfaces in the real world tend to lie in similar depth planes; smooth gradients in depth of the visual field are far more common than sudden changes or discontinuities. The second level of analysis is simpler and involves obtaining an algorithm, that is a formal set of steps or procedures, which will carry out the

Figure 1. Rene Descartes (1596-1650).

computation. The third level involves physical realization of the algorithm. This may be implemented with the neurones of the brain or by a computer chip. According to Marr it does not matter whether the hardware is biological machinery or a computer as far as the computational or algorithmic levels of the information processing problem are concerned. We know that the problem of global stereopsis is solved by neurones in the visual cortex at the back of the brain, but it could also be solved by a computer chip that was appropriately designed to compute the global stereopsis algorithm.

The distinction between the three levels of analysis of an information processing device (including the brain) can be illustrated by considering a very interesting property of some neurones in the eye. The nerve cells in the retina that send visual information from it to the brain along the optic nerve are referred to as retinal ganglion cells. In some species these neurones are directionally selective, that is a ganglion cell fires impulses at a high rate when an object is moved past the overlying light-sensitive rod receptors that are connected to it in one direction (therefore called the preferred direction); when the object moves in the opposite direction the ganglion cell

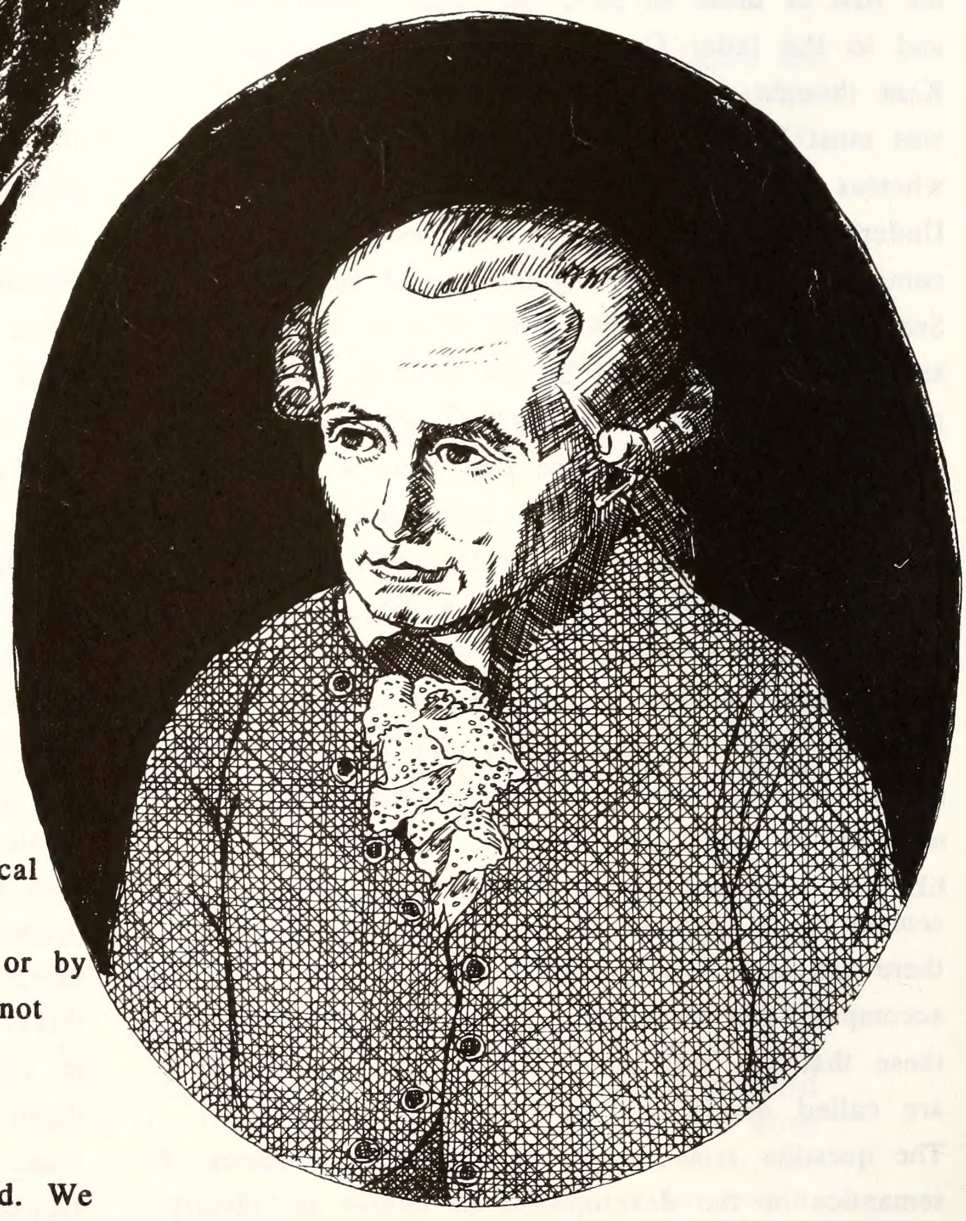

Figure 2. Immanuel Kant (1724-1804).

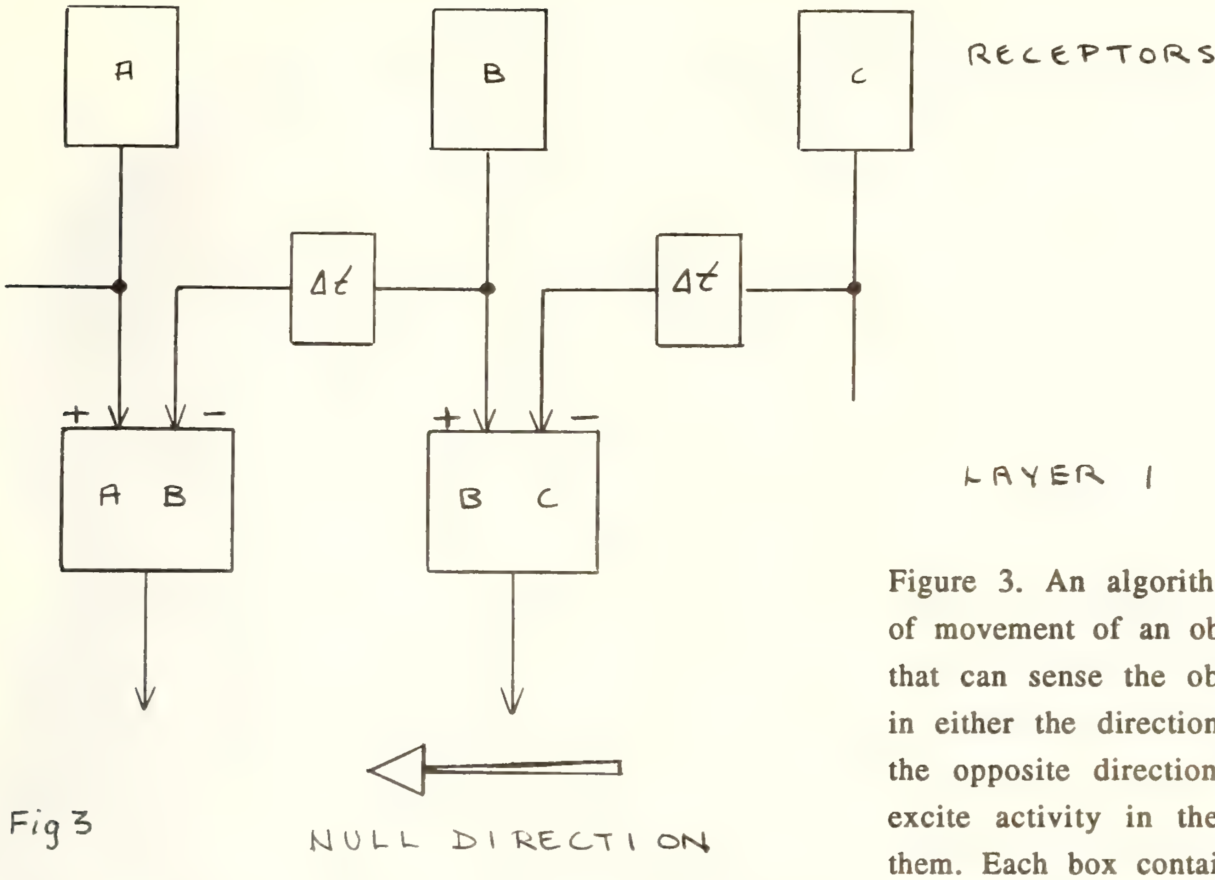

Fig 3

Figure 3. An algorithm for detecting the direction of movement of an object. A, B and C are receptors that can sense the object, which moves over them in either the direction indicated by the arrow or in the opposite direction. These receptors can each excite activity in the units immediately beneath them. Each box containing a At is a unit which if excited by the receptor connected to it will after a delay of length At prevent excitation of the adjacent unit in the null direction indicated by the arrow. The way in which this algorithm functions to give directional selectivity is explained in the text.

Figure 4. The retina provides a biological means of implementing the directional selectivity algorithm given in Figure 3. The equivalence between the retinal neurones and the elements that compose Figure 3 are: the rod receptors (R) are the receptors; the bipolar cells (B) are the layer 1 units; and the horizontal neurones (H) are the At units. The output units, not shown in Figure 3, are the retinal ganglion cells (G).

Fig 4

does not fire (and so this is called the null direction). An algorithm for this process has been developed and is shown in Figure 3. When an object moves in the null direction, electrical activity from an excited receptor (say C in Figure 3) excites (+) a unit in the layer immediately beneath it while at the same time inhibiting (-) the next unit in the null direction; each receptor in turn, namely C, B, and A carries out this process as the object moves over them. The delay units (shown as At in Figure 3) determine that the inhibitory process stops the excitatory activity from A and B moving through these gates if motion is in the null direction but reaches the gates too late to produce such inhibition if motion is in the preferred direction.

Implementation of this algorithm in the biological material of the retina is as follows (see Figure 4). The direct excitatory pathway in the retina is from the photoreceptors (R), through the bipolar cells (B), to reach the retinal ganglion cells (G). This excitatory pathway is modulated by the horizontal cells (H); they receive an excitatory input from the photoreceptors, and conduct this laterally in the null direction through their long dendrites (Td) to inhibit the bipolar cells in adjacent regions. The wiring of the retinal neurones in this way prevents excitation of the ganglion cells when an object moves in the null direction but does not prevent such excitation when an object moves in the preferred direction. Comparison of Figure 4 with Figure 3 shows that the horizontal cells are equivalent to At delay units and the bipolar cells to the layer one units. It is clear that the algorithm of Figure 3 can be implemented in either the wet-ware of neurones or the hard-ware of a silicon chip.

Although it has been stressed that the algorithm for global stereopsis as well as that for directional selectivity may be implemented using neurones or chips, they may also be carried out using a computer. It was Alan Turing (Figure 5) who first showed that a machine could in principle be built to solve a particular algorithm; this is often called the Turing machine. Turing went on to show that a Universal Machine could be built that could simulate any machine, so that this Machine could solve any algorithm. The present day computer is such a Machine. It can run as different kinds of computer (an IBM or a MacIntosh) if programmed appropriately and therefore can solve any algorithm. Suppose that all syntactical structures, from the rules governing the arrangement of words and phrases in sentences to those governing the logic followed by devices for directional selectivity, are algorithmic: it follows then that they can be implemented on a computer. The retina acts as one kind of Turing machine when it solves the algorithm for directional selectivity.

Figure 5. Alan Turing (1912-1954).

The idea that different parts of the nervous

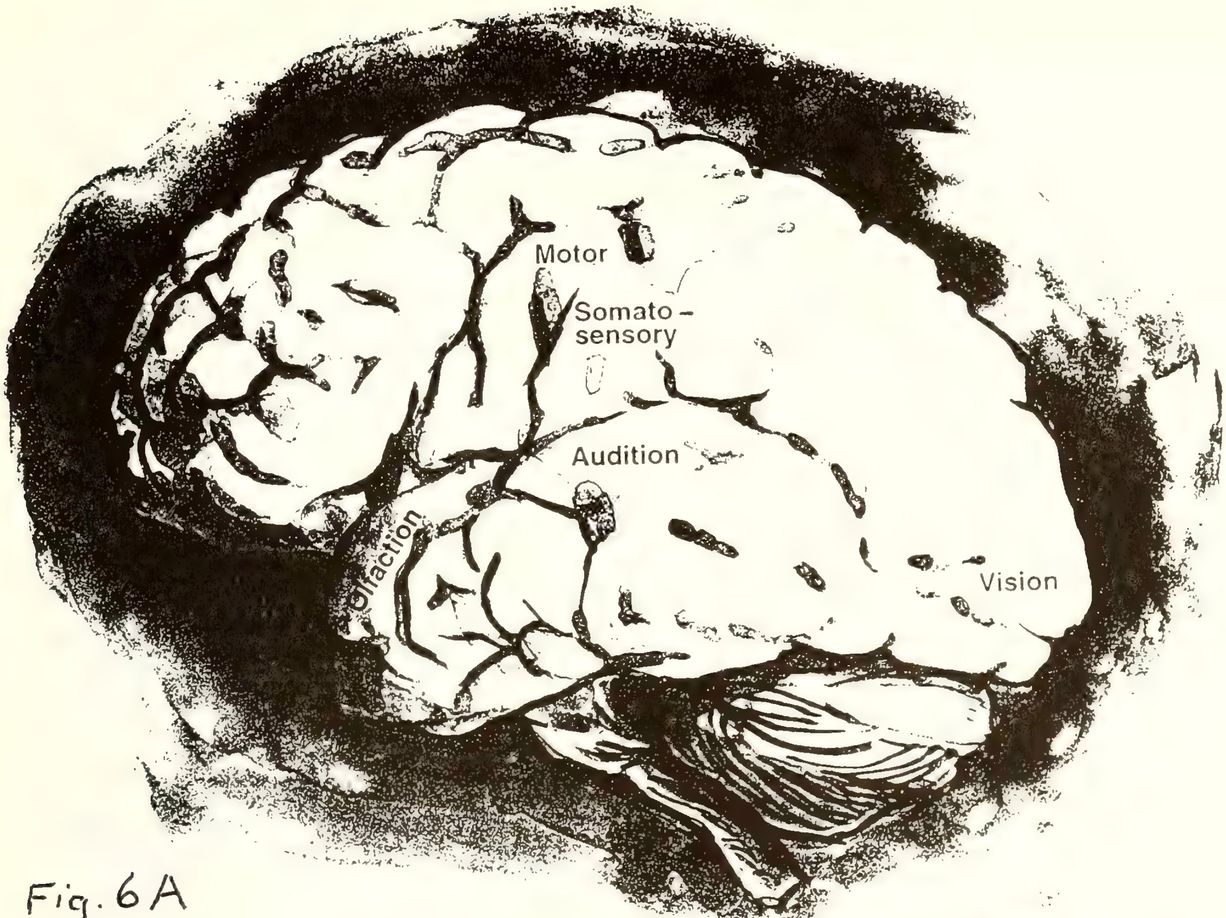

Fig. 6A

Fig. 6B

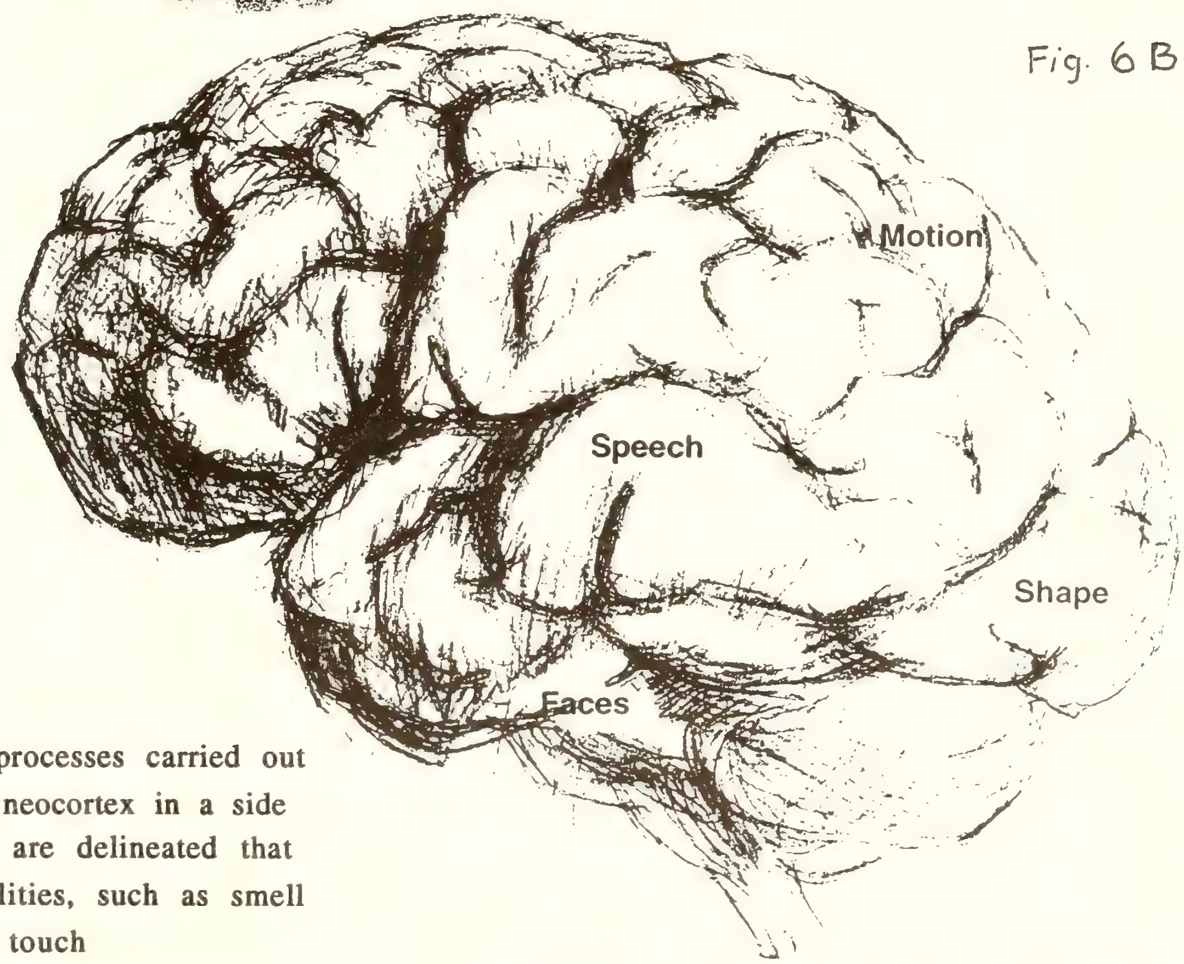

Figure 6. Possible algorithmic processes carried out in the neocortex. A, shows the neocortex in a side view; several different regions are delineated that process different sensory modalities, such as smell (olfaction), sound (audition), touch (somatosensory) and sight (visual); also shown is the area of the neocortex that is responsible for movement of the limbs (motor cortex; M). B, shows different regions of the neocortex that are thought by some to be involved in the solution of a number of different algorithms ; these include reconstruction of the images of faces in the inferior temporal lobe ; the recategorization of phonemes, that is, the sounds that distinguish one word from another and their order, in Wernicke's speech area; computing the motion of an object in the parietal cortex ; and finally, computing shape from movement in a region anterior to the visual cortex.

system, such as the retina, have an objectively formal syntactical structure like that of a computer programme has been challenged by John Searle. He uses the word 'computational' in the context of solving the algorithmic problem rather than in Marr's sense of posing the problem and the constraints associated with it. His challenge goes like this: the computational state of the directional selectivity mechanism refers to the identification of the synapses in the system that are solving the algorithm for this problem. But it is we that make this selection, which is then not intrinsic to the retina like its temperature or mass, but assigned to it. Every neurone in the retina has thousands of synapses on it, so that it is impossible to look at the efficacy of each of these and determine that it is part of a directional mechanism algorithm. The algorithmic properties of the retina are assigned to it and are not intrinsic. The fact that algorithms can be implemented on different kinds of hard-ware, such as a retina or a silicon chip, simply shows that the computational processes of the algorithm are not intrinsic properties at all. They depend on interpretation from outside the system considered. That the computational patterns are carried out on a computer or in a nervous system does not explain how they work. Searle arrives at the important conclusion that syntax is an observer relative notion. According to this view then what seems to be a relatively straightforward proposition, namely that different parts of the nervous system solve different sets of algorithms which are objectively posited in the system like its temperature and mass, is erroneous. The proposition that a system has computational properties, intrinsic to it like those of its physical properties, is incorrect. Accordingly, syntax is observer relative.

NEURONAL NETWORKS IN THE BRAIN AND SEMANTICS: WITTGENSTEIN AND SEARLE.

Neuroscience has shown that different parts of the neocortex (Figure 6A), the mantle of the brain, process different aspects of our experience of the world and of our reactions to those experiences. For example, the process of determining the shape of an object from the way it is shaded is known to occur in an area of the neocortex that lies just in front of the primary visual cortex (compare Figure 6B with Figure 6A). Computing the movement of an object occurs in the parietal cortex whereas identification of the object occurs in the inferior temporal lobe (Figure 6B). The ability to process sounds that distinguish one word from another as well as their order occurs in the part of the neocortex called the area of Wernicke (Figure 6B). Dennett claims that each of these different areas of the neocortex is carrying out its task by solving an appropriate algorithm and that they are therefore acting as computers. Furthermore the semantic content of these processes, their meaning, is the process itself. This is equivalent to saying that the meaning that we attach to the identity of an object is part of the algorithm that is carried out by the appropriate neurones in the inferior temporal lobe used for this purpose (Figure 6B). In this case meaning is ascribed to the computational process that carries out the algorithm. Algorithms have been devised for carrying out the process of identifying objects from their shading (as in the area anterior to the visual cortex, Figure 6B); these are based on the kinds of information that this area is likely to receive from the visual cortex, and are framed in such a way as to offer a plausible description of what the neurones in this part of the brain do. Is it possible that such a computation also contains within it the meaning of the algorithm?

Searle has a now famous argument that meaning is not embodied in algorithmic processes. Even if the idea that different parts of the brain possess intrinsic computational properties as a consequence of the way the neurones are connected is admitted, which Searle does not, the algorithmic process they carry out could have no meaning associated with it that is intrinsic, that does not lie outside the computational process. Searle's argument involves the idea of the Chinese Room. Consider a number of people each of whom has been taught one component of the process involved in manipulating Chinese symbols

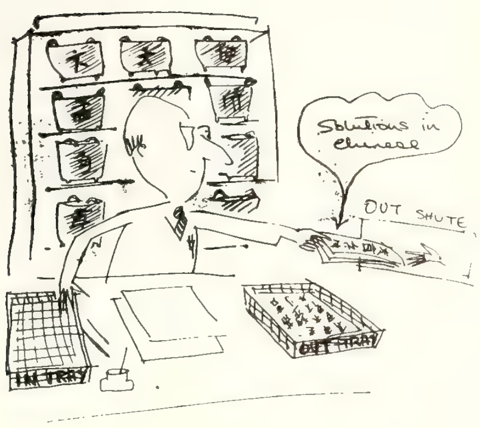

Figure 7. The Chinese Room. Searle proposed that in this room a series of manipulations are made to the symbols that comprise a Chinese manuscript so as to render the manuscript into English. Each set of manipulations is made to the entire manuscript according to a set of instructions in English. The important point is that the person in the room does not know what is going on in the room; he is only aware of the rules that must be followed in carrying out the choice of Chinese characters according to the English instructions. Although questions in Chinese may be posed and answered in Chinese, there is no understanding involved by the person in the room.

according to instructions in English. This room receives Chinese texts through one delivery port, the same receptionist being used to receive each text; a text is then handed onto a person whose job it is to carry out the first process in manipulating the symbols according to the list of written instructions in English. This may involve certain rules of syntax being applied: for instance certain symbols in Chinese might be exchanged for certain other Chinese characters, each of which may be found in a separate basket. This person in turn passes this text onto the next person in the chain, and so on until the penultimate text is received by the last person who, after carrying out the last process on the text, delivers a completed manuscript to the exit port of the room. None of the persons in the room have any understanding of the processes carried out by any of the others, nor of the overall process. Yet an effective response to the original Chinese text may be achieved by this procedure even though the process is without meaning to those in the room. Now Searle suggests that the same argument holds if just one person carries out all these processes in the room; that is manipulates symbols according to a set of rules (syntax; see Figure 7). For instance to those outside the room, some of the text presented may require questions on specific subjects to be answered. These are eventually supplied, and considered as answers to those outside the room, without having any meaning to those in the room(Figure 7). Searle's point is that an algorithm, such as that involved in manipulating the Chinese symbols, is

computed without meaning being ascribed to any element of the process. This of course holds if we replace the persons in the Chinese Room with a neuronal network that carries out the computation. The Chinese Room only has meaning for the person who designed it in the first place; it does not arise from the workings of the room itself.

Wittgenstein (Figure 8), the greatest philosopher since Kant, argued further that meaning only arises as a consequence of some form of dialogue which presupposes a sociological setting. As there are an infinite number of such settings for each of us, and unique to each of us, then semantics cannot be algorithmic. For example, when a person talks about the colour "blue', they do not have an image of "blue" in their brains to which they refer and which has somehow become imprinted there. Rather it is the application of the word "blue" to an object in a sociological setting that determines the character of the images which the person accepts as "blue". The meaning of this word is maintained by its public applications not by reference to some template in the brain. Wittgenstein maintained that this also holds for words like "pain" which do not apply to public objects: their meaning is maintained by sociological interactions involving use of the word. It follows that semantics is embedded in an enormous variety of discourses and so cannot be algorithmic.

A further argument that meaning cannot be achieved by purely algorithmic processes is due to the mathematician Roger Penrose. His argument depends on the famous demonstration by Godel that any reasonably sophisticated system of axioms gives rise to statements that are obviously true but cannot be proved to be true within the particular system generated by the axioms. One can "see" that the statement is not formally provable within the system. As a consequence, Penrose claims that the concept of mathematical truth cannot be encapsulated in any formalistic scheme. If this is true then no formal system of syntax can give rise to understanding, such as in the above case of identifying the truth of the statement. A computer or a neural network in our brains, which is following a formal set of rules, cannot then understand. This lies outside the system.

Figure 8. Ludwig Wittgenstein (1889-1951).

THE PROBLEM OF A NEURONAL BASIS FOR QUALIA: EDELMAN AND DENNETT.

The attempt to incorporate qualia into an algorithmic procedure is much more difficult to conceive of than the possibility that syntactical or even semantic processes are algorithmic. The awareness of your mother in a room, sitting at her sowing, may involve qualia of movement, particular colours, the sound of her voice and the smell of her perfume. Such memories may be

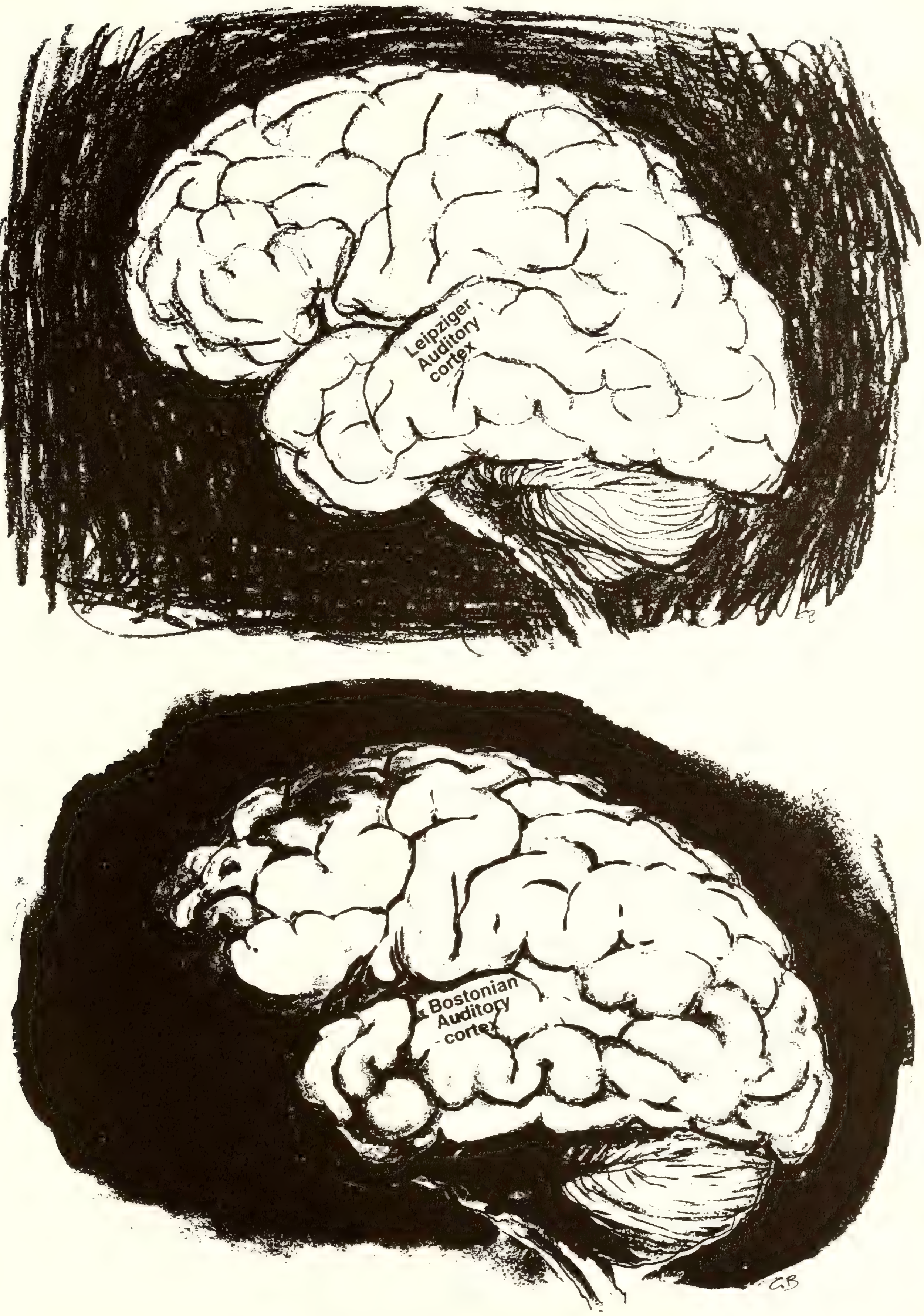

Figure 9. Qualia and the neocortex. The question is can the qualia associated with an auditory cortex listening to a fugue in Leipzig at the time of Bach (Leipziger auditory cortex in the upper panel) be reconstructed in the cortex of a contemporary listener in Boston (Bostonian auditory cortex in the lower panel) . Dennett claims that a list of the differences between the two periods and places, although very long, is possible. It is feasible then for the Bostonion brain to possess the qualia of the Bach fugue experienced by the Leipziger brain. This idea is refuted by Wittgenstein, who has shown that an infinite number of differences are involved, which are furthermore peculiar to each individual at any time.

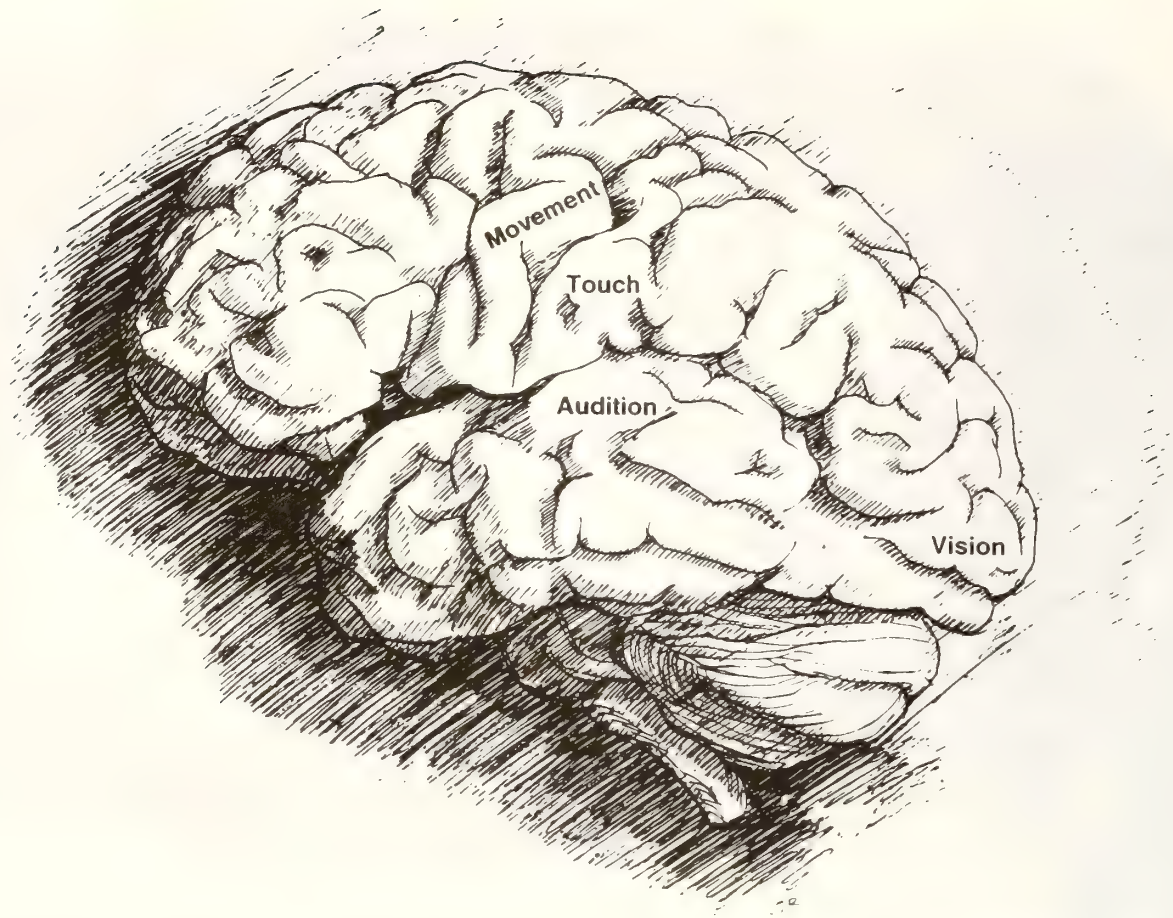

Figure 10. The neocortex is viewed by Dennett as a parallel computational processor of algorithms. The algorithms are each implemented in series by neurones in the neocortex. The location of some of the parallel processors associated with the implementation systems of audition, vision, movement and touch are indicated. Consciousness is then regarded as the computational process itself. According to Searle, however, these computations are not intrinsic properties of the brain but are observer dependent; that is the experimentalist chooses the particular sets of synapses and neurones that he believes could carry out the computation which realizes the algorithm which is very different from measuring intrinsic properties such as the temperature of the neurones. Furthermore, Searle uses the Chinese Room argument to show that meaning cannot arise from within an algorithmic process itself; this can only be ascribed to the person that designed the algorithm in the first place. If the brain is a parallel computational processor then according to Searle the meaning of these computations can only arise from outside the processors.

stored in the parietal cortex and the temporal lobes, where they have been built up over a huge number of experiences involving your mother in different sociological settings since the time you were born. It was a triumph of seventeenth century physics to rid qualia from objects for the purposes of describing their intrinsic properties, such as weight and temperature, which could be used as variables in different physical laws. Qualia are an essential ingredient of consciousness. The elimination of qualia for the purposes of reporting on those properties of an object that are useful in the formulation or carrying out of so-called physical laws is to eliminate mind from nature. Wittgenstein pointed out that it is not possible to have knowledge of what we call qualia without consideration of the sociological setting in which this knowledge is obtained. In the words of Edelman," One cannot render obvious to a hypothetical qualia-free animal what qualia are by any linguistic description."

It is possible, according to Dennett, to reconstruct qualia if they are merely "dispositional

states of the brain". In this case qualia could be incorporated into algorithmic processes. For example the brain may consider information about wine in the form of taste, colour and smell. The disposition for a particular preference could be genetically built into the wiring of our neurones through evolutionary pressures; for example the colour red may give a complex of conflicting emotional responses, arising from now largely redundant genetic information that red fruit is good and red snakes are bad. A more complex example, which attempts to face up to the criticisms of Wittgenstein, involves consideration of the qualia experienced when listening to a Bach fugue. An attempt is made to contrast the qualia of a middle-class person from Leipzig listening to a fugue at the time of Bach with that of a middle-class Bostonian listening now (Figure 9). Dennett suggests that if a list is made of the differences between these periods and places, then it should be possible to interchange the qualia associated with the fugue between the two periods and places. However Wittgenstein, Searle and Edelman have indicated that there are an effectively infinite number of such differences which are unique to an individual's experiences. Qualia cannot then be objectified in this way. They cannot be accompanied within a theory that draws up lists for each person of their entire life's experiences, embedded as this is in language and a unique sociology.

To what extent then has neuroscience illuminated our understanding of syntax, semantics and qualia? Neuroscientists certainly assume that the early processing of sensory information, like that giving directional selectivity in the retina, is syntactical. Furthermore that algorithms can be found which carry out the appropriate computation, and that neurones exist which are connected up so as to carry out this computation. Yet it must be said that at this time Searle's criticism of syntax as involving the execution of algorithms holds: no complete synaptic wiring diagram of a set of neurones subserving the implementation of an algorithm has been obtained; all wiring diagrams to this time assume that anatomical synaptic connections are functional. This is very unlikely. Therefore Searle's criticism concerning the subjective routine followed in the choice of synapses involved in integrative processes has not been refuted. As far as semantics is concerned, the claim that meaning arises from the computational process enacted in solving an algorithm seems to be refuted by the Chinese Room argument. Neuroscience at present has nothing to say about meaning. It may arise at levels of the neocortex that are so far removed from what we do know something about, namely the neural basis or early sensory processing, that it is as yet beyond neuroscience.

Neuroscience may have something to say about qualia. The neocortex contains different areas each specialized for dealing with different senses such as vision, audition, touch (somatosensory) as well as with distinguishing the sounds for different words (Wernicke's area) and with many other processes (Figure 10). There is some evidence to suggest that memories associated with a particular sensory modality are eventually stored in areas of the neocortex that are closely associated with that modality. For example, memory for a particular face is stored in the inferior temporal lobe, the area of the neocortex concerned with visually identifying objects. The possibly arises then that the qualia associated with your mother, such as her complexion, the sound of her voice and the smell of her perfume, are stored respectively in the visual cortex, the auditory cortex and the olfactory cortex. The many other qualia with which you identify your mother would likewise be stored in the appropriate part of the cortex, depending on the modality involved. In this way different components of the immense number of experiences you have participated in with her would be maintained in a distributed set of modules throughout the cortex. Your feelings and sensations about your mother would then require that these modules be activated in parallel. What the mechanism is for such activation and more importantly, how such a distributed system could

give rise to the holistic experience of a set of mother qualia, is considered in the next paper.

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THE BINDING PROBLEM AND CONSCIOUSNESS

Neuroscience of Attention

Max R. Bennett

When viewing an attractive scene, such as a garden, one is aware of particular trees, shrubs and perhaps even flowers. It is extraordinary that we can attend to just these named objects in the garden amongst the enormous number of visual impressions that our retinas receive from the scene. For there is nothing really to distinguish the photons which reach our retinas from say the bark on a tree and those from the shrubs surrounding it. What is it then that allows us to experience the tree as an holistic structure? What neural processes bind together its trunk, boughs and leaves into a single entity which is readily identifiable from the surrounding and sometimes partially enveloping shrubs? This is referred to as the binding problem. Clearly the binding problem can be considered at other levels of holistic experiences. For example, a breeze may occur that produces a rustle as it passes over the leaves of the tree. In this case we may be conscious of both the visual identity of the tree, involving our visual cortex, as well as the sound of the rustle of its leaves, involving our auditory cortex. How is it in this case that we have an holistic experience which involves two quite different areas of our brains? This essay is concerned with what solutions to the binding problem are now offered by neuroscience.

NEURONAL GROUPS AND 40 Hz OSCILLATIONS.

Thomas Young (Figure1) conceived the idea that the neocortex might be thought of as being made up largely of neuronal groups. A neuronal group is a set of neurones in the neocortex which possess a very large number of synapses that interconnect the individual neurones in the group. This large number of intrinsic connections is in contrast to the relatively sparse number of synapses in the group that brings in extrinsic connections from other nearby groups or from distant groups elsewhere in the neocortex (Figure2). A neuronal group can be identified functionally by means of electrical recordings. An electrode placed outside of the neurones in some part of the neocortex records a field potential, which is the cumulative effect due to the separate impulses firing in the group of neurones within a short distance of the electrode (Figure3, first trace); another electrode is now placed inside a neurone, near the first electrode; if the impulse firing of this neurone is at the same frequency as that of the local field potential and occurs in phase with this field potential, then we are recording from a neurone within a neuronal group (Figure3, third trace).

Gerald Edelman has argued at length that neuronal groups are to be considered as building blocks in the solution of binding problems. The very large number of horizontal connections between different parts of the neocortex are considered by him to subserve reciprocal connections between neuronal groups. Such recurrent horizontal connections occur both between groups within a selected modality as well as between modalities. For example, the neuronal groups may be in the same area of the visual cortex (Figure4). They may be in different areas of the visual cortex. They may even be in different hemispheres, such as the visual cortex in each hemisphere, connected by the very large number of axons that join the two hemispheres called the corpus callosum. Neuronal groups may also be connected across different modalities ; for example vision and touch (in the somatosensory cortex; Figure4).

NEURONAL GROUPS PARTICIPATE IN SOLUTION OF THE BINDING PROBLEM IN VISUAL CORTEX

Figure 1. Thomas Young (1773-1829)

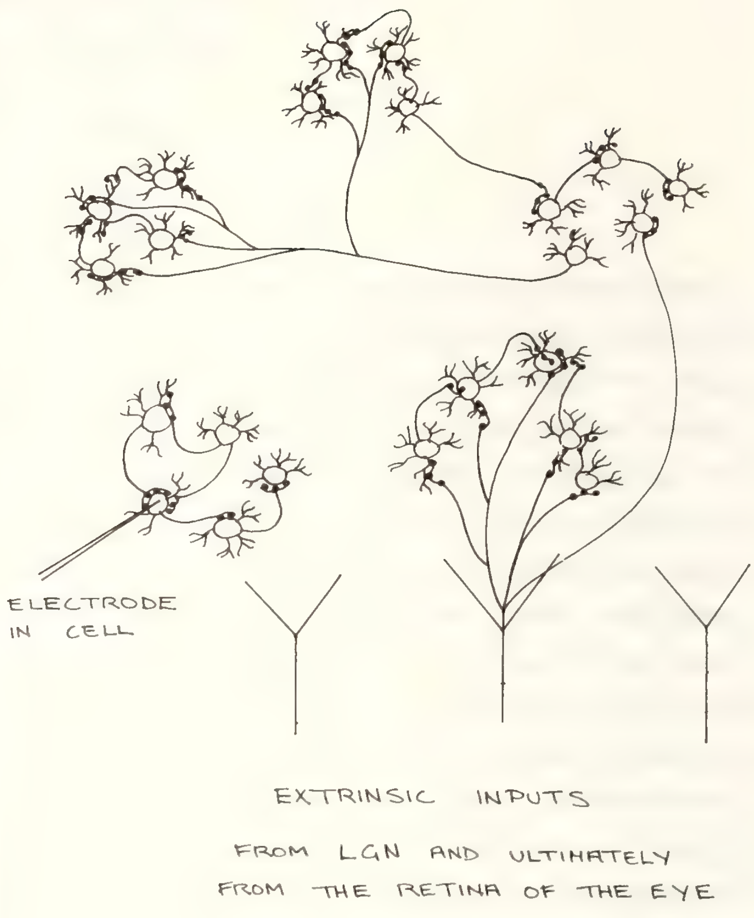

Figure 2. Diagram illustrating the synaptic connectivity of neurones that constitute neuronal groups. Neurones within a particular group are identified by the large number of synaptic connections between the members of the group in comparison with the relatively low number of connections between groups. Extrinsic connections from sources that are a long way away from the groups in question are also shown. These extrinsic connections could come ultimately from the retina, so that the neuronal groups shown are in the visual cortex.

Wolfgang Singer has provided evidence that there is a dynamic coupling of appropriate neuronal groups in the neocortex with the solution of a binding problem. Consider, for example, two vertically orientated light bars moving at the same speed in the same direction past the eyes. There will be a tendency for these to appear as a single object, that is bound together as one. Each of these bars at a particular time excites two different neuronal groups in the visual cortex (Figure4), each connected with the appropriate parts of the retina that are being excited by one of the bars. The photomicrograph in Figure5 shows the position of two such neuronal groups in the visual cortex of a cat: the black areas in this flat mount of the surface of the cortex indicate columns of neurones, of which only the tops are shown, that are particularly responsive to vertical contours. Microelectrodes are placed in the neuronal groups positioned at the white arrows about 7mm apart on the cortex and these record the oscillatory responses to the movement of the white bars as shown in A (and on an expanded time scale in B). The oscillatory field potential in one neuronal group, which gives a measure of the common impulse activity amongst

the neurones within the group, fires at the same frequency (about 40Hz) and in phase with the field potential in the other neuronal group, even though this is 7mm away. No such coupled firing would be expected for neuronal groups at such a distance. The experience that the two light bars are one object is correlated with the fact that the neuronal groups in the visual cortex that are excited independently by images of each of the bars on the retina are joined in a dynamic way, as indicated by a common frequency and phase of their neuronal firing. This is an example of the transient excitatory coupling of two neuronal groups within the same area of neocortex, in this case visual area V (see Figure4).

Singer has also shown that there is interhemispheric synchronization of activity in the visual cortex when a binding problem is being solved for a visual object. Suppose a single light bar is sufficient to stimulate three different neuronal groups in the visual cortex of one hemisphere that are about 1mm apart (Figure 6A); the synchronization of the impulse firing and the phase of this firing, as measured by three different electrodes, can be shown by means of what is called an cross-correlogram (Figure 6B); if a periodic pattern is discernible in the cross-correlogram then this indicates that the signals are correlated and gives information as to the common frequency and phase in the correlation (Figure 6B). The cross-correlograms for the recordings from the three electrodes in either hemisphere show a strong oscillatory modulation in the same frequency range of about 40Hz, even though they may be separated by as much as 2mm (Figure 6B). Cross-correlograms of the recordings from electrodes in both hemispheres show similar correlations to that in Figure3B indicating that both hemispheres participate in the solution of the binding problem for the single white bar. This is not the case however if the group of axons that join the two hemispheres (the so-called corpus callosum) is cut. The cross-correlogram for recordings from the two hemispheres is now devoid of any periodic pattern and is flat (Figure 6C), indicating that the firing of neuronal groups due to the light bar in each of the

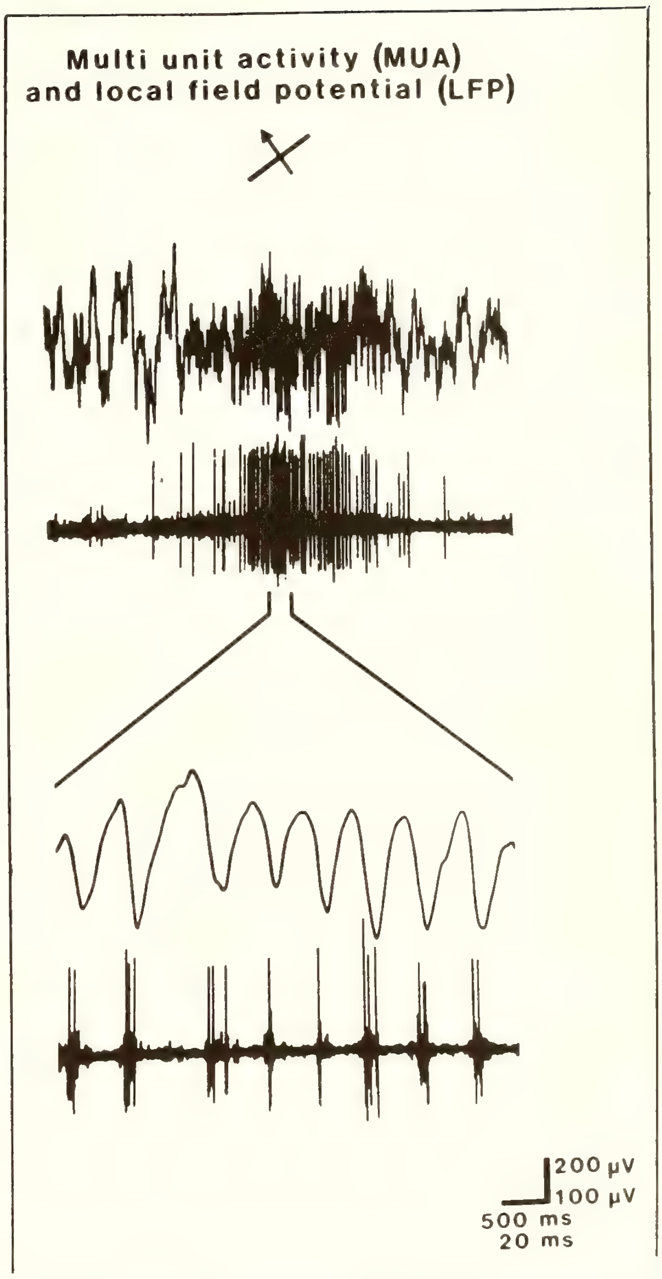

Figure 3. Neuronal groups can be identified functionally using recording electrodes.The first trace shows recordings with an electrode placed within a cluster of neurones; in this case the electrode records the summed electrical impulse firing from all the neurones in its vicinity, called a field potential. In the second trace another electrode is placed inside a neurone so that it only records the impulse firing from the impaled cell; it will be noted that there is heightened activity at the same time in both the first and second traces.The third trace shows a small segment of the second trace on an expanded time scale; it is now evident that the field potential is oscillating at about 40 Hz, that is the neurones in the vicinity of the electrode must be firing at this frequency and in phase; this is confirmed by the fourth trace, that shows the individual impulses in the impaled neurone which are firing in very fast bursts at intervals of about 25 ms, that is at 40 Hz. Data from Singer,1991.

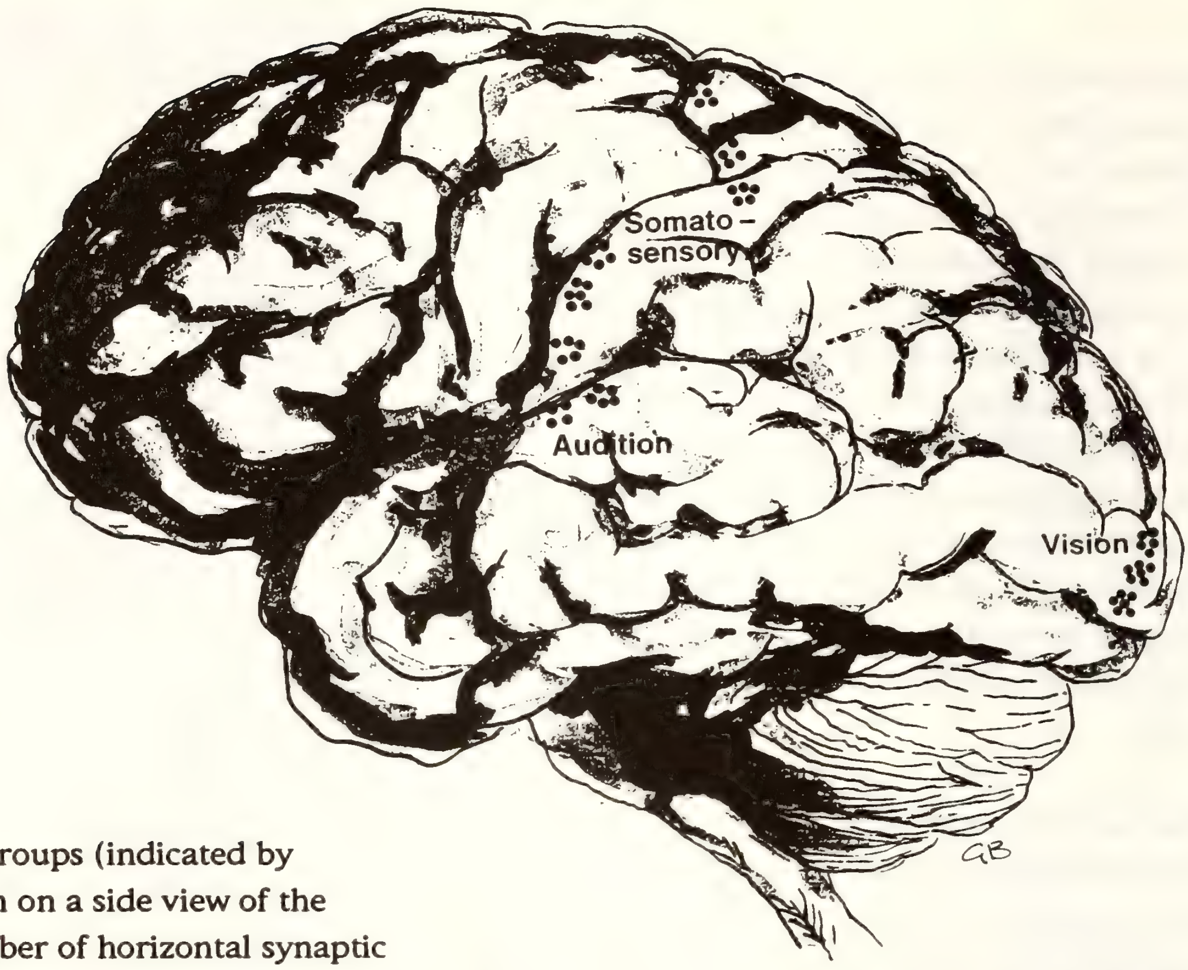

Figure 4. Some neuronal groups (indicated by clusters of dots) are shown on a side view of the brain. The very large number of horizontal synaptic connections between the myriads of neuronal groups in the neocortex are not shown. Sets of groups are shown, however, in the visual cortex , in the auditory cortex , and in the touch (somatosensory) cortex.

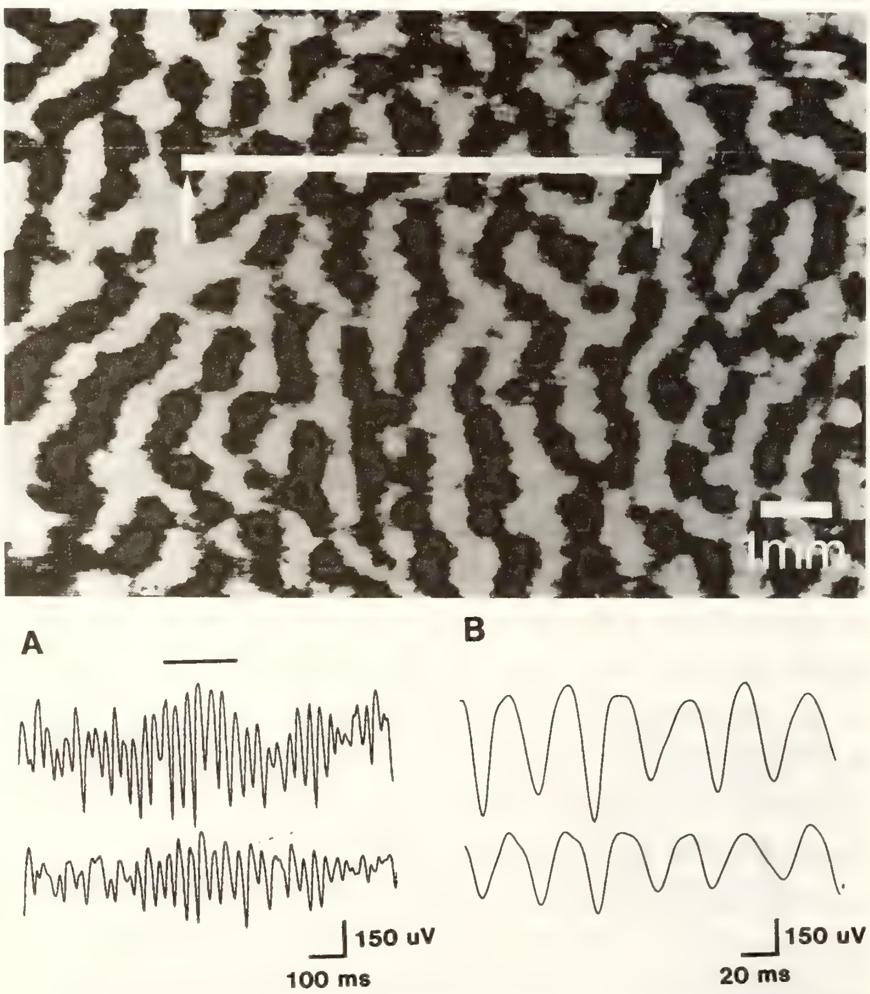

Figure 5. Synchronized neuronal firing of two different groups of neurones in the visual cortex of a cat (area 17) during the observation of two vertically oriented light bars moving with the same speed and in the same direction. The bars are sufficiently far apart to be seen by two quite different parts of the retina which project to two neuronal groups in the visual cortex that are 7mm apart (as indicated on the photomicrograph of the surface of the visual cortex by the arrows). Recordings made with electrodes placed in the vicinity of these two neuronal groups are shown in A. The average impulse firing of the neurones in each of the groups (as shown by the field potentials) is oscillatory. B, shows on an expanded time scale that the oscillations of the two groups is at 40 Hz and that they are in phase. It is predicted that these two light bars would then appear as a coherent object to the cat as the neuronal groups excited by them are coupled in their firing in this way. Data in the photomicrograph from Siegrid Lowel; electrophysiological data from Gray and Singer, 1991.

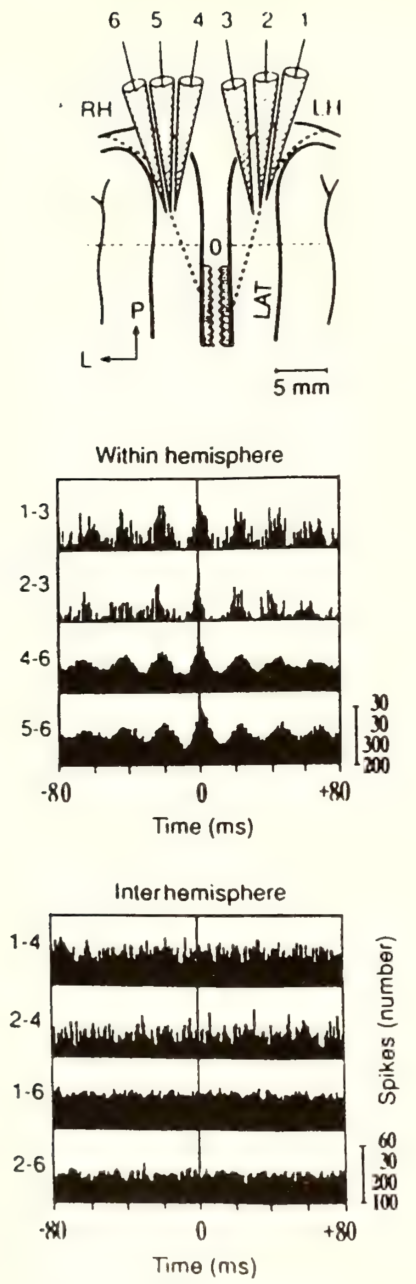

Figure 6. Synchronized neuronal firing of three different groups of neurones in each hemisphere of the visual cortex of a cat. (A), shows the position of three electrodes in area 17 of each hemisphere; the distance between the electrodes is about 1mm, and each electrode is given a number. (B), shows the cross-correlograms for the field recordings of pairs of neuronal group activity indicated by the electrode positions 1-3,2-3,4-6,5-6; the oscillatory responses are synchronized within each hemisphere, even though two of the neuronal groups recorded from are 2 mm apart; the correlograms show that the synchronized frequency is about 40 Hz. (C), the cross-correlograms between the activity of neuronal groups in different hemispheres (pairs 1-4,2-4,1-6,2-6) show no temporal correlations when the corpus callosum has been cut, that is the correlograms are flat (the corpus callosum is a group of axons which allows the activity in one hemisphere to be conveyed to the other); this is in contrast to cross-correlograms between the activity of neuronal groups in different hemispheres before the corpus callosum is cut, which show 40Hz synchronized activity like that in B. Data from Engel,Konig, Kreiter and Singer,1991.

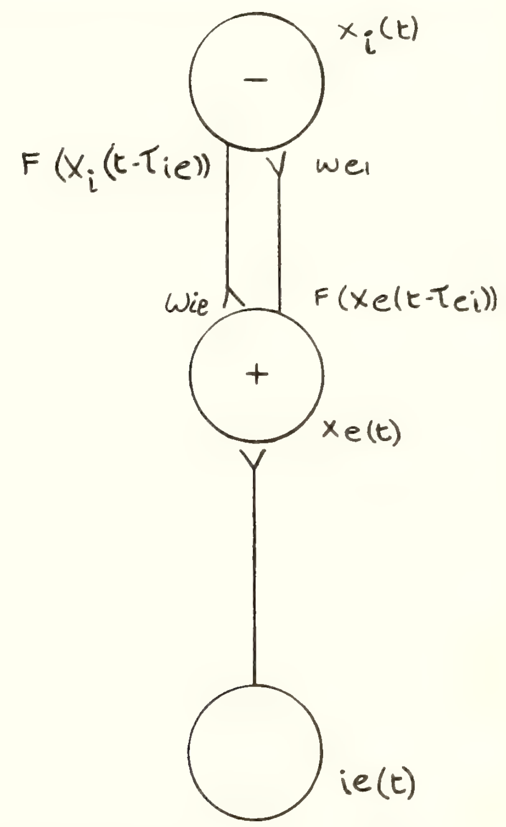

Figure 7. Modelling of a neuronal group by a delayed non-linear oscillator. This figure shows an excitatory unit (+) with an excitatory synaptic connection to an inhibitory unit (-) which in turn has an inhibitory synaptic connection back onto the excitatory unit; in addition there is an extrinsic input to the excitatory element. The symbols on the units and their connections refer to the following properties which these have: $x_e(t)$ indicates the activity of the excitatory unit; $x_i(t)$ indicates the activity of the inhibitory unit; F(x) gives the output function of a unit; w_{ei} gives the strength of the synapse from the excitatory unit to the inhibitory unit; w_{ie} gives the strength of the synapse from the inhibitory unit to the excitatory unit; T_{ei} gives the time delay built into the connection between the excitatory unit and the inhibitory unit; T_{ie} the time delay between the inhibitory unit and the excitatory unit; ie(t) indicates the extrinsic input to the element. This element will oscillate at a characteristic frequency determined by the values of the parameters. Data from Konig and Schillen, 1991.

hemispheres is no longer correlated. The corpus callosum then mediates the dynamic connections between the two hemispheres that most likely participate in the solution of the binding problem.

MECHANISMS OF DYNAMIC COUPLING BETWEEN NEURONAL GROUPS

Several plausible models are now available that explain how dynamic coupling between neuronal groups might arise during solution of the binding problem by the neocortex. For simplicity a neuronal group may be modelled as a single oscillatory element, like that shown in Figure7. This element oscillates as a consequence of the coupling of an excitatory unit, that is one that only forms excitatory connections, with an inhibitory unit, namely one that only forms inhibitory connections; each of the connections possesses delays built into them. An input element allows for extrinsic connections to the oscillatory element. Activity of a single oscillatory element depends on the delay time in the connections, on the level of input from the extrinsic element, and on the strength of the coupling which each connection makes with a unit in the element. These elements are referred to as delayed non-linear oscillators.

Synchronization between oscillatory elements in a layer, equivalent to synchronizing the activity between neuronal groups across a part of the neocortex, is achieved by coupling the excitatory unit of one element with the inhibitory unit of another (Figure8). Consider, for example, a set of elements laied out in a rectangular matrix of 14 by 7 elements. At first all the inhibitory connections between the elements have been made but none of the excitatory connections; in addition, the oscillatory activity of each element (for which T1 is the period length of oscillation of an isolated element) is desynchronized by a noisy extrinsic input. Figure 9 shows the activity of 20 units chosen at random from the matrix both before excitatory connections are made between nearest-neighbour elements in the matrix (time less than0) and after the connections are made. Note that the elements become synchronized on making the excitatory synaptic connections, despite the high noise level being maintained (Figure9). This effect can also be illustrated by means of an activity-phase map, like that shown in Figure10: each circle represents an element in the 14 by 7 matrix, with the diameter of the circle proportional to the activity of the element and the degree of shading proportional to the oscillation phase. The upper matrix shows the elements under conditions of excitatory coupling of adjacent elements; under these conditions maximum activity is observed for each element and they are all in phase; when these excitatory connections are broken, the activity of most of the elements declines and they are mostly out of phase, as shown in the lower matrix. This example shows how the appropriate coupling of inherently oscillatory elements leads to maximizing their activity and brings them all into phase, a necessary condition for a correct model of the dynamic coupling of neuronal groups.

How then do these delayed non-linear oscillators provide insights into the solution of the binding problem? Consider a two-dimensional array of such elements,coupled together by excitatory connections, each representing a neuronal group; these groups might be taken to analyze in visual cortex a small part of the visual scene projecting onto a small part of the retina (Figure11). The effect of coherency in the stimulation of different members of these elements, giving rise in a real cortex to synchronization of their activity associated with the solution of a binding problem, is considered for two short light bars; these are taken to provide extrinsic excitation of the elements shown in Figures11 A and B; note that the light bars are at different distances apart in A and B. Another example is provided by a continuous light bar equal in length to the two short bars (Figure11C). Figures11D,E and F show the cross-correlations for the numbered elements in Figures11A,B and C respectively: The dashed line shows the cross-correlation within the stimulus bar segments (numbers 1-2 and 3-4 in Figures11 A,B and C) and the continuous line the cross-correlations between the bar segments (numbers 2-3). The cross-correlations between bar segments are equivalent to

stimulus coherency, that is the two bar segments are bound together as one object. It will be noted that this occurs most strongly for the light bar segments when they are reasonably close together, as in Figure11B, and shown by the large size of the cross-correlation in Figure11E (continuous line for numbers 2-3). When the bar segments are relatively far apart, as in Figure 11A, the cross-correlation is very small (Figure 11D; continuous line for numbers 2-3). The cross-correlation for the numbers within both the short bar segments as well as the long bar segments is always high (that is for numbers 1-2 and 3-4). This example shows that correlated impulse firing of neuronal groups that are separated in space may be expected if there is some form of stimulus coherency.

ATTENTIONAL MECHANISMS SUBSERVING THE BINDING PROBLEM.

Although mechanisms of the kind described above may be involved in the solution of the binding problem, they do not necessarily provide an explanation of how it is that we attend to a particular object in our visual field. There may be a number of different objects in the visual field, the images of each falling on our retina; the visual neocortex may then solve the binding problem for each of these but what then is the mechanism involved in the process of attending to only one of these objects? The mechanism of selective attention is well illustrated by the experiment shown in Figure 12. Recordings are made of the electrical activity of a neurone in part of the monkey neocortex that subserves vision; the neurone fires impulses when the image of an object falls over any part of a fairly large area of the retina, indicated by the large dotted rectangle in the Figure; this area is called the receptive field of the neurone. A red bar (hatched bar in Figure12) presented anywhere over the area of this receptive field produced vigorous firing of the neurone, whereas a green bar (open bar in Figure12) failed to excite the neurone at all. The animal was then taught to attend to different locations within the receptive field, using an appropriate reward procedure. In the first experiment, the monkey attended to the location of the red bar (the attention being indicated in Figure12 by a searchlight), whilst a green bar was also introduced into the receptive field; under these conditions the neurone fired vigorously, as shown in the lower part of Figure12A. In the second experiment, the monkey was taught to attend to the location of the green bar, so ignoring the location of the red bar that was still maintained within the

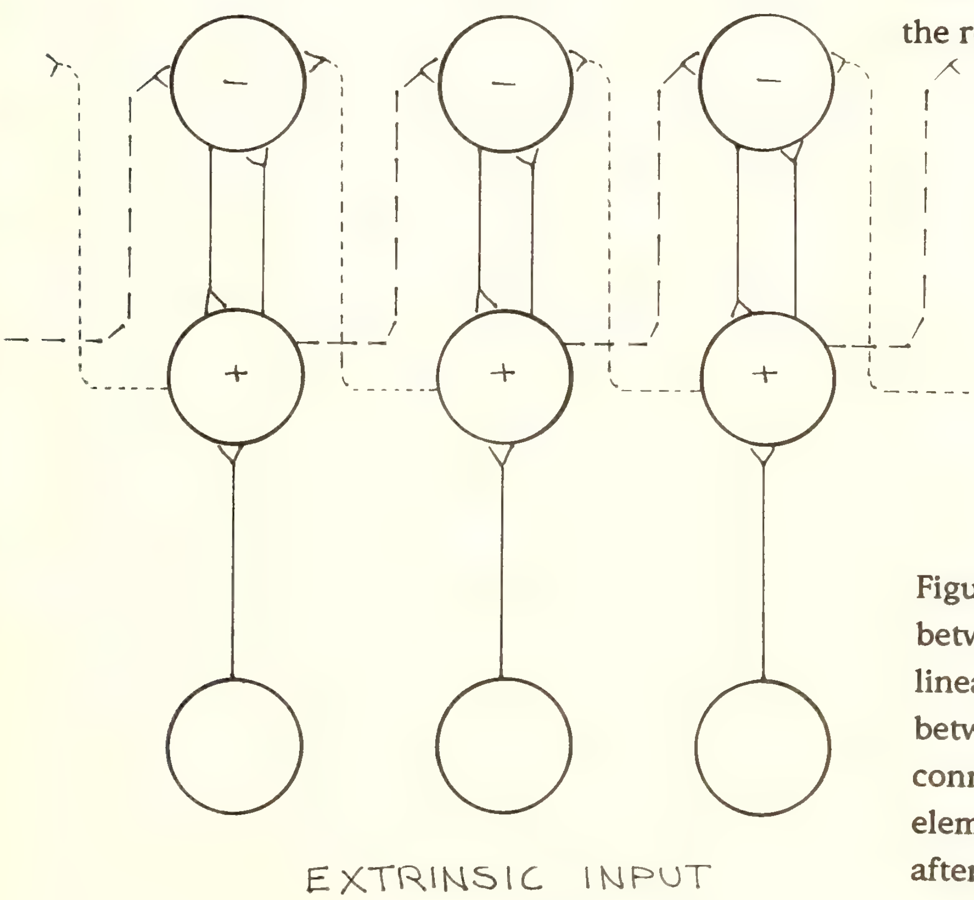

Figure 8. Modelling of the horizontal connections between neuronal groups by coupled delayed non-linear oscillators. In this case synchronization between elements can be obtained by synaptic connections between the excitatory unit of one element and the inhibitory unit of another. Figure after Konig and Schillen, 1991.

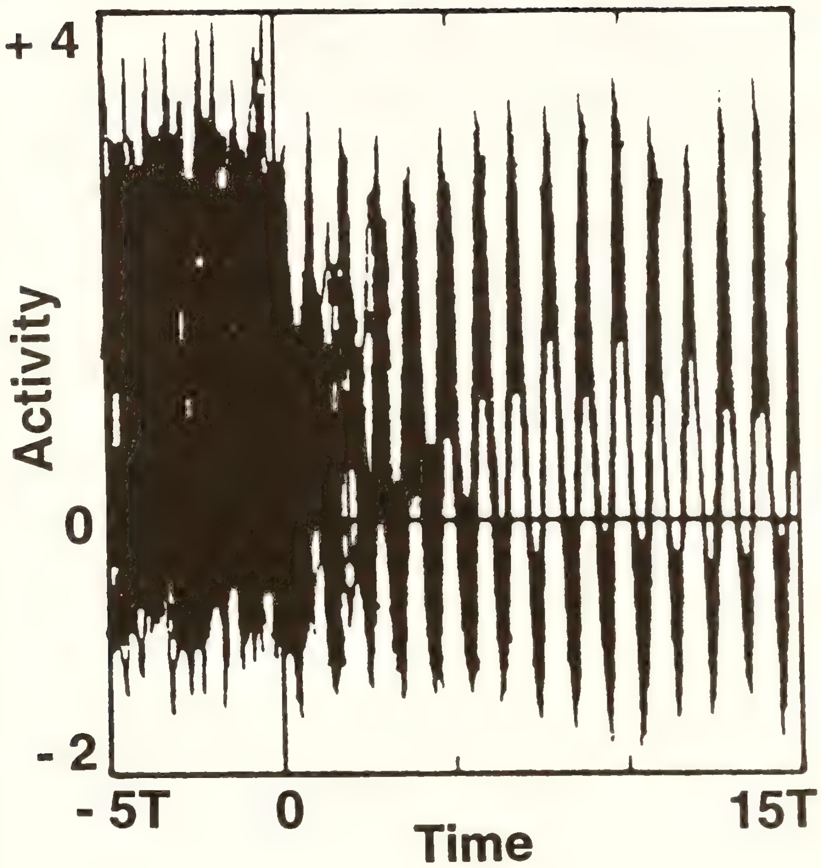

Figure 9. The activity of 20 delayed non-linear oscillator units (each representing a neuronal group) chosen at random from a two-dimensional matrix of 14 by 7 coupled elements (which may be considered to be representing a large array of neuronal groups, for example in the visual cortex). This graph shows that if the excitatory connection between elements is not connected, and there is a high noise input from an extrinsic element, then activity of the 20 chosen elements is highly desynchronized (if T is taken as the length of the period of oscillation of an isolated element, then the desynchronized time is taken from -5T to 0). At time 0 these connections were made and all 20 elements started to oscillate together in phase. Data from Konig and Schillen, 1991.

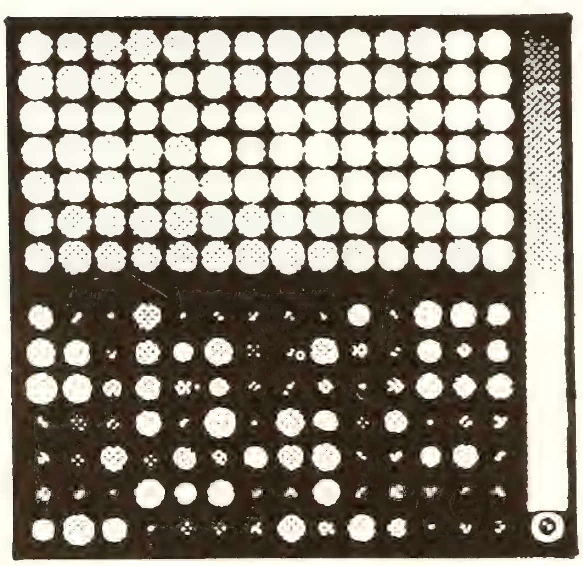

Figure 10. An activity phase map of all 14 by 7 non-linear oscillator elements (or neuronal groups). The diameter of each circle is proportional to the activity level of the unit and the shading gives the phase of the activity. When all the nearest neighbour excitatory couplings are made between nearest neighbour elements (of which there are 8 for each element) then all elements fire with maximum activity and all are in phase (upper matrix). When these connections are broken, the activity of many of the elements falls to near zero, and those that remain active are generally out of phase (lower matrix). Data from Konig and Schillen, 1991.

receptive field (Figure12B); in this case the neurone fired at a much lower rate (lower part of Figure12), even though the red bar was still within the receptive field of the neurone and might then be expected to give rise to vigorous firing of the neurone. It is clear that lack of attention to the location of the red bar greatly decreased the rate of firing of the neurone. This experiment shows that neuronal mechanisms that are responsible for attention must be engaged, possibly in addition to those that solve the binding problem, in order for a neurone that is involved in high-order visual processing to fire impulses at an optimal rate.

We have seen that reciprocal connections between neuronal groups in neocortex can lead to 40Hz synchronized oscillations of action potential firing in a particular set of groups that are solving a

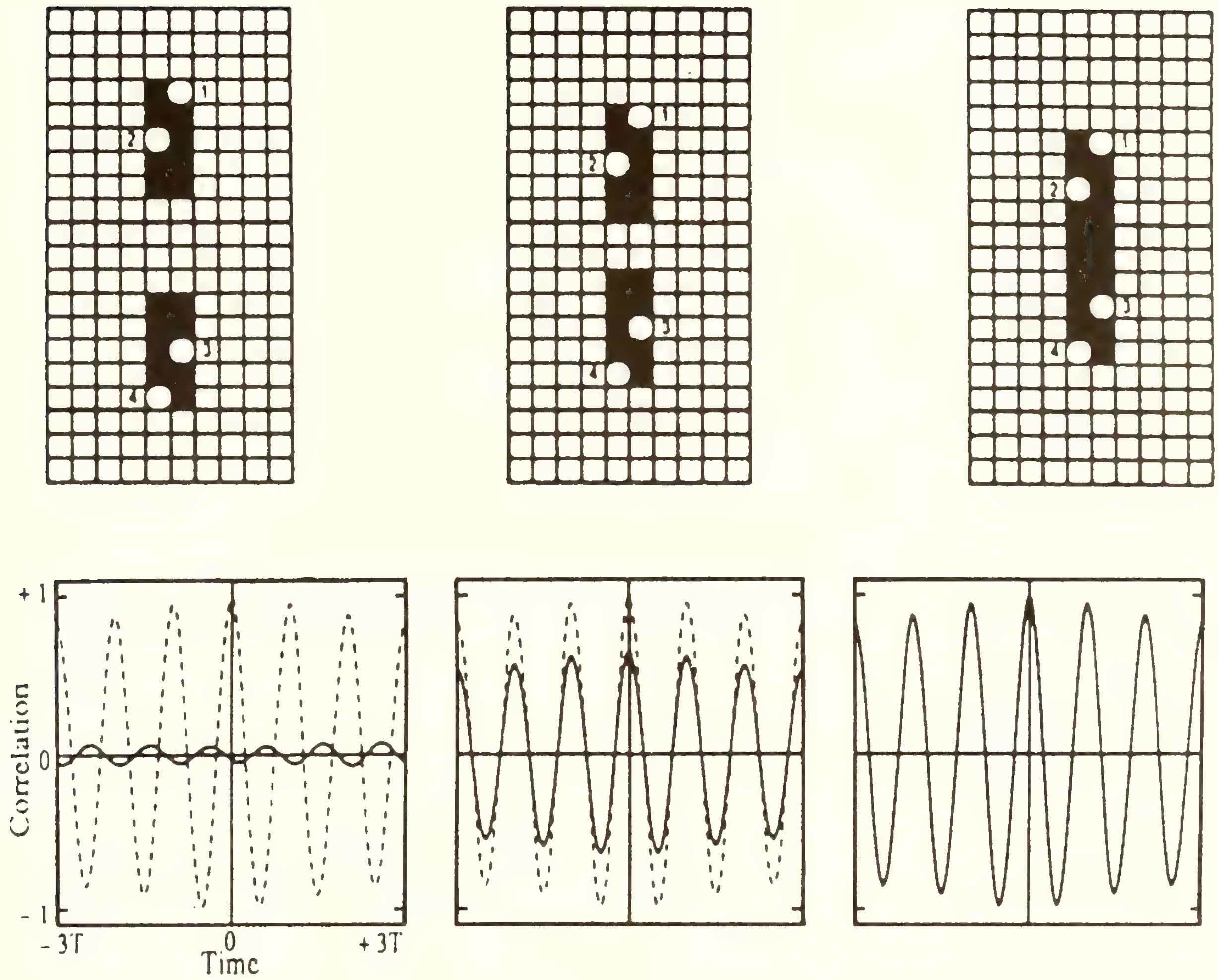

Figure 11. The effect of stimulus coherency on the activity of a matrix of non-linear oscillator units (representing coupled neuronal groups in the visual cortex). (A), shows the array of elements that are excited by extrinsic inputs representing two light bars; these are three elements apart and have numbered elements 1/2 and 3/4 respectively.(B), shows the array of elements that are also excited by two light bars but this time they are only two elements apart and have numbers 1/2 and 3/4 as before. (C), shows a single white bar of the same total length as the two single bars with elements 1/2 and 3/4 as before. (D), (E) and (F) give the cross-correlations between elements 1/2 and 3/4 within the bars (dashed line) and between elements 2/3 between the bars (continuous line) for each of (A), (B) and (C) respectively. Note that the cross-correlations are very strong between the separate bars even when they are seperated by two non-excited elements (B). Data from Konig and Schillen, 1991.

binding problem. What then are the mechanisms that determine which particular solutions of the binding problem will be attended to and not others. This is equivalent to asking, in the case of visual phenomena, what objects in the visual field for which the binding problem has been solved in neocortex will be allowed to reach consciousness? Francis Crick has suggested that the attentional mechanism for this process is centred in the thalamus. The sensory inputs to the neocortex arise from the thalamus (Figure13). The principal neurones of the thalamus in turn receive connections from such sources of sensory information as the retina. The principal neurones in the thalamus are surrounded by a concentric layer of neurones called the reticular complex; this receives connections from the neocortex as well as from axons that leave the thalamus on their way to the neocortex (Figure13). Most importantly, these reticular neurones make connections with the principal neurones of the thalamus that are only inhibitory (Figure13). Within the thalamus itself

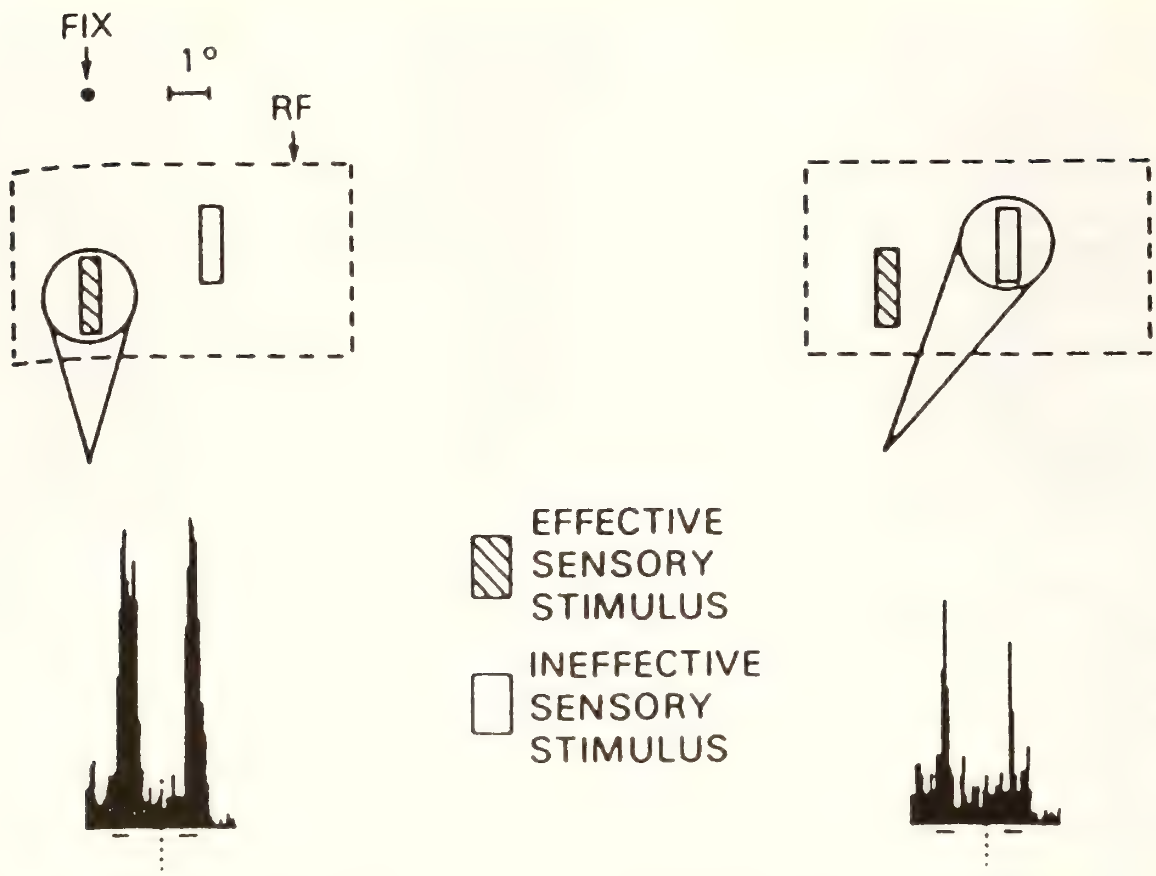

Figure 12. The effect of selective attention on the firing of a neurone in the visual cortex of a monkey. This neurone fires impulses when certain visual phenomena fall on any part of the area of the retina indicated by the large broken rectangle. One of these is a vertical red bar (hatched rectangle); however the neurone does not fire at all if the image of a vertical green bar (open rectangle) falls onto this part of the retina. If the monkey is taught to attend to the area indicated by the circle (searchlight) as in (A), which includes the red bar, then the neurone in the visual cortex fires at a high rate as shown in (A). If, however, the monkey is taught to attend to a different area which this time includes the green bar as in (B) then the firing of the neurone falls well below the maximum rate, even though the red bar is still being projected onto this part of the retina (B). Attention to the red bar is required in addition to it being in the correct part of the retina in order for this neurone to fire off at a high rate. Data from Moran and Desimone, 1985.

there is another set of neurones, called the pulvinar (Figure13), which also receives connections from the neocortex as well as projecting extensively to the neocortex; these pulvinar neurones, like those of the reticular complex, make inhibitory connections with the principal neurones of the thalamus. Crick has argued that if we are conscious of a particular aspect of the visual field, such as our mother's face, then an attentional mechanism is operating that involves the reticular complex and the pulvinar. Neurones in these structures depress the sensory input from the thalamus to the neocortex that is not relevant to solving the binding problem concerning your mothers face. The neuronal groups in visual neocortex that are solving this problem are therefore given an excitatory advantage over those solving other binding problems as a consequence of the activity of the principal neurones in the thalamus.

The discovery of principal neurones in the thalamus that fire impulses in the frequency range from 30 Hz to 40 Hz, and which possess an underlying rhythmicity of about this frequency (Figure14), does much to support the idea that the thalamus participates in the generation of 40Hz oscillations in the neocortex. Further support for the idea comes from studies on patients with

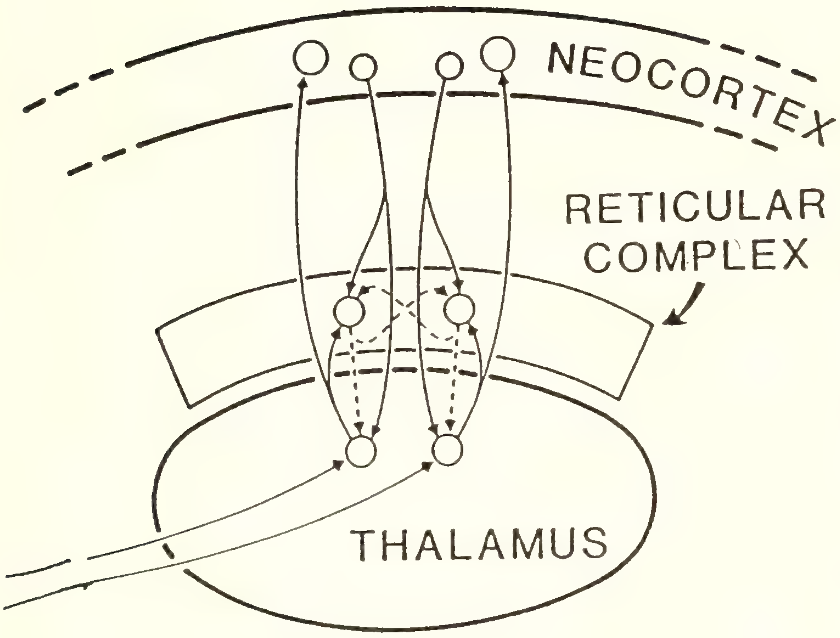

Figure 13. Sensory inputs to the neocortex, such as vision, must project through the thalamus (with the exception of the sense of smell). This involves these inputs first connecting to principal neurones in the thalamus; these neurones in turn make connections with the input neurones in the neocortex as shown. Sets of neurones in or around the thalamus called the reticular complex neurones and the pulvinar neurones also connect to the principal neurones of the thalamus, as shown. The reticular and pulvinar neurones have the effect of inhibiting the principal neurones, so decreasing the activity of these due to the sensory inputs. Furthermore, the reticular and pulvinar neurones receive inputs themselves from the neocortex, as well as from the brain stem, as shown. These neurones are therefore under both neocortical and brainstem control, so that these regions of the brain can modulate the input of sensory information from the thalamus to the neocortex. Diagram partly from Crick, 1984.

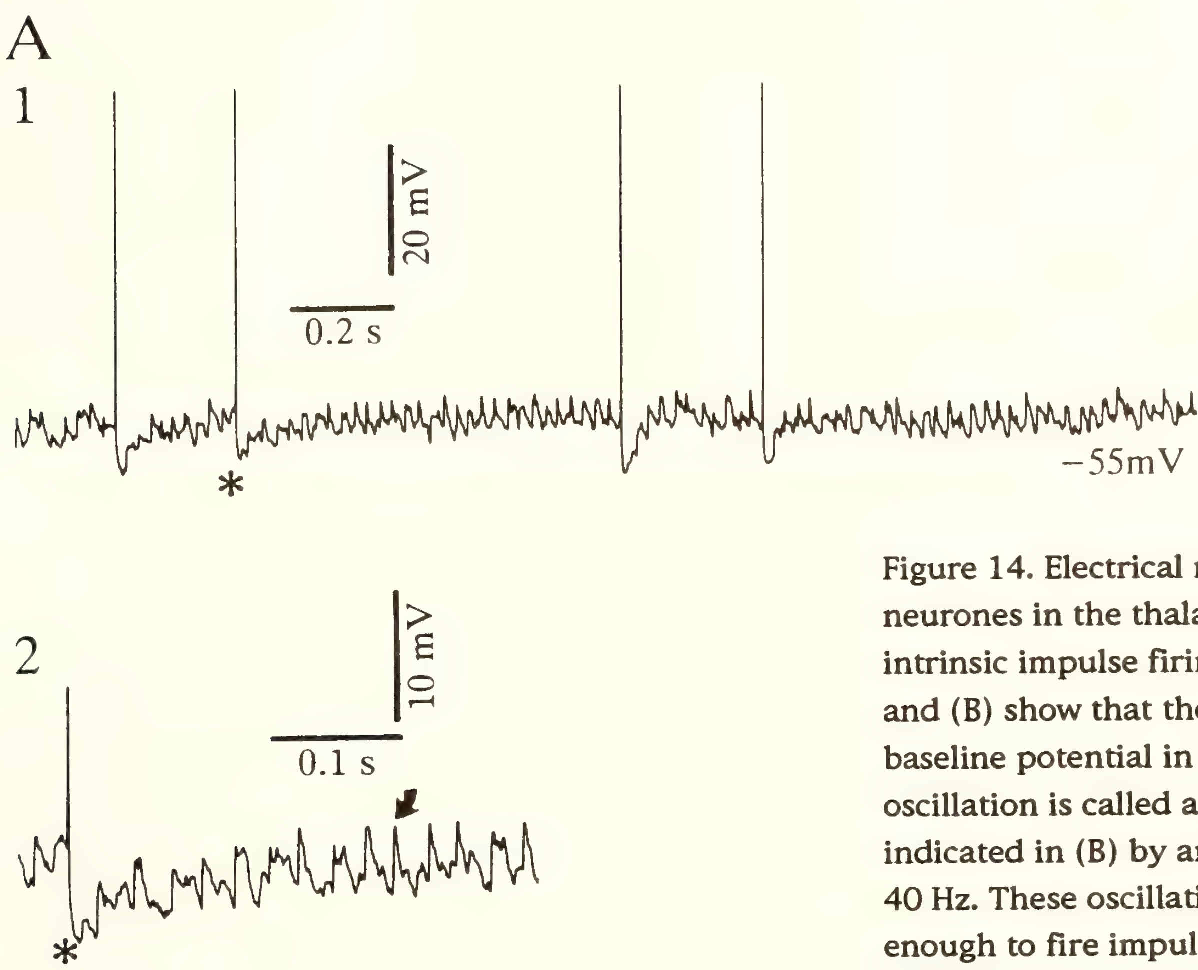

Figure 14. Electrical recordings from two principal neurones in the thalamus showing that these have intrinsic impulse firing rates of about 40 Hz. (A) and (B) show that there is an oscillation of the baseline potential in these neurones (each oscillation is called a prepotential, one of which is indicated in (B) by an arrow) that occurs at about 40 Hz. These oscillations are sometimes large enough to fire impulses, two of which are indicated by *. These results suggest that at least part of the 40 Hz oscillations recorded in the neocortex arise from this kind of oscillatory activity in the thalamus. Data from steriade, Dossi, Pare and Oaksen, 1991.

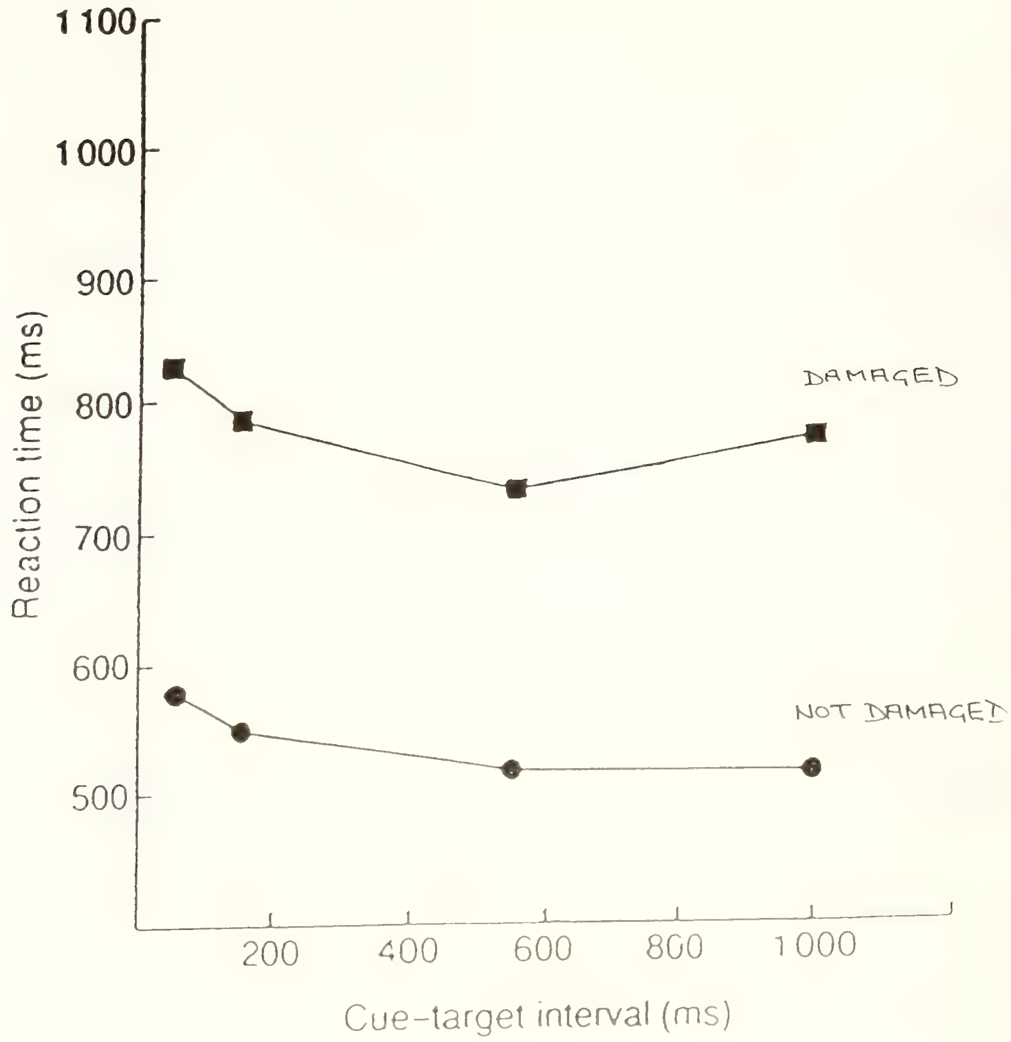

Figure 15. Evidence that the thalamus contains neurones that are necessary for attentional behavour. This graph shows the reaction times of patients with damage to the reticular complex or the pulvinar on one side of their brain (filled squares). This is compared with the reaction times when the side of the brain that is not injured is engaged in the measurement (filled circles). The horizontal axis indicates the interval between presenting a cue and that of a target to be identified at a random interval later; the vertical axis gives the reaction time between the presentation of the target and its identification by the patient. The reaction times are several hundred milliseconds longer for patients with thalamic injuries.

damage to the reticular complex or the pulvinar. Defects in attention are readily discerned in such patients. For example, the reaction times of such patients to the site of a particular target presented at random times after presentation of a clue may be used to determine an attentional deficit. Figure 15 shows the results of such an experiment: the vertical axis on the graph shows the patients' reaction times to respond to visual targets, and the horizontal axis gives the intervals between presentation of the cues and that of the targets. If the cue-target combination was presented to the part of the visual field subserved by the injured thalamus the reaction time was always about one-fifth of a second slower than when the cue-target combination was presented to the part of the visual field subserved by the normal thalamus on the other side of the brain (Figure 15). This was the case no matter what the interval between presentation of the cue and that of the target (Figure15). Attentional mechanisms appear to involve the reticular complex and the pulvinar of

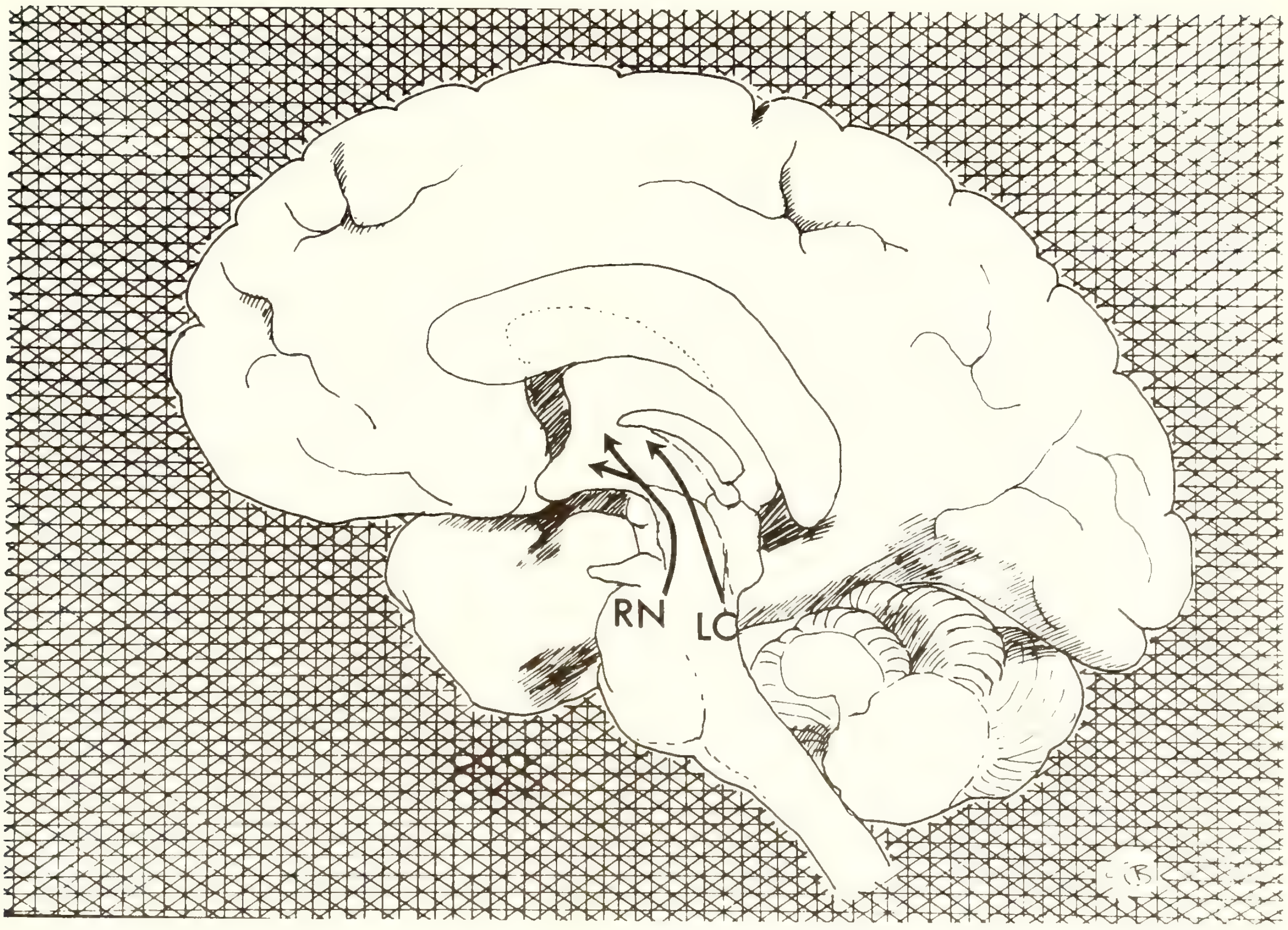

Figure 16. Brain stem sets of neurones that project to the reticular complex and the pulvinar of the thalamus. This medial view of the brain shows the sets of brain stem neurones in question, the raphe nucleus (RN) and the locus coeruleus (LC) (with another set, the peribrachial nucleus not shown). The raphe neurones secrete the transmitter substance serotonin from their terminals in the thalamus, the locus coeruleus neurones the transmitter noradrenaline and the peribrachial neurones the transmitter acetylcholine. Brain stem neurones are associated with determining the general levels of excitability of the thalamus and therefore of the cortex, such as that associated with the sleep/wake cycle.

the thalamus in humans as well as in other animals as Crick first suggested. Crick called his theory of attention the searchlight hypothesis, as in a sense the reticular complex and the pulvinar promote only a small proportion of the activity that reaches the thalamus on its way to neocortex: this increased activity can then be likened to a searchlight that lights up a part of the neocortex. The patches of neocortex that are solving binding problems for the objects attended to will then possess much greater activity than other patches. A final set of coherent oscillations then emerges only for those neuronal groups which the searchlight has sought out. These then constitute consciousness of the attended objects.

If the reticular complex and pulvinar of the thalamus participate in attentional mechanisms in this way, then what determines which particular groups of neurones in these regions of the thalamus are active? Put another way, what determines that we attend to a particular object over another in our visual field, this attending process requiring the enhanced activity of just a particular set of neurones in the reticular complex and the pulvinar of the thalamus? The brain stem, at the top of the spinal cord, contains three groups of neurones that project to the reticular complex, and which have a powerful modulating effect on the neurones there. These groups of neurones belong to the locus coeruleus, the raphe nucleus and the peribrachial nucleus (Figure16). The neurones in these groups release from their nerve endings the transmitters

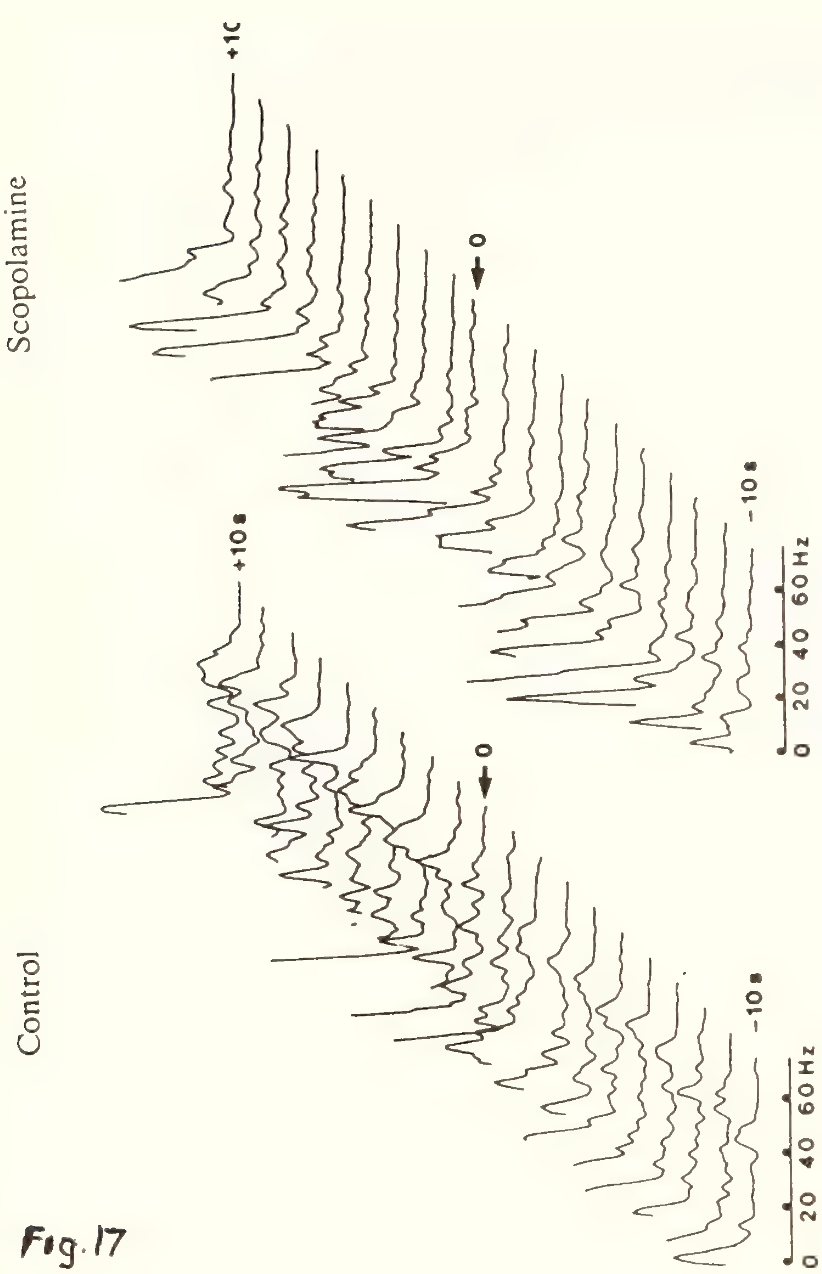

Fig. 17

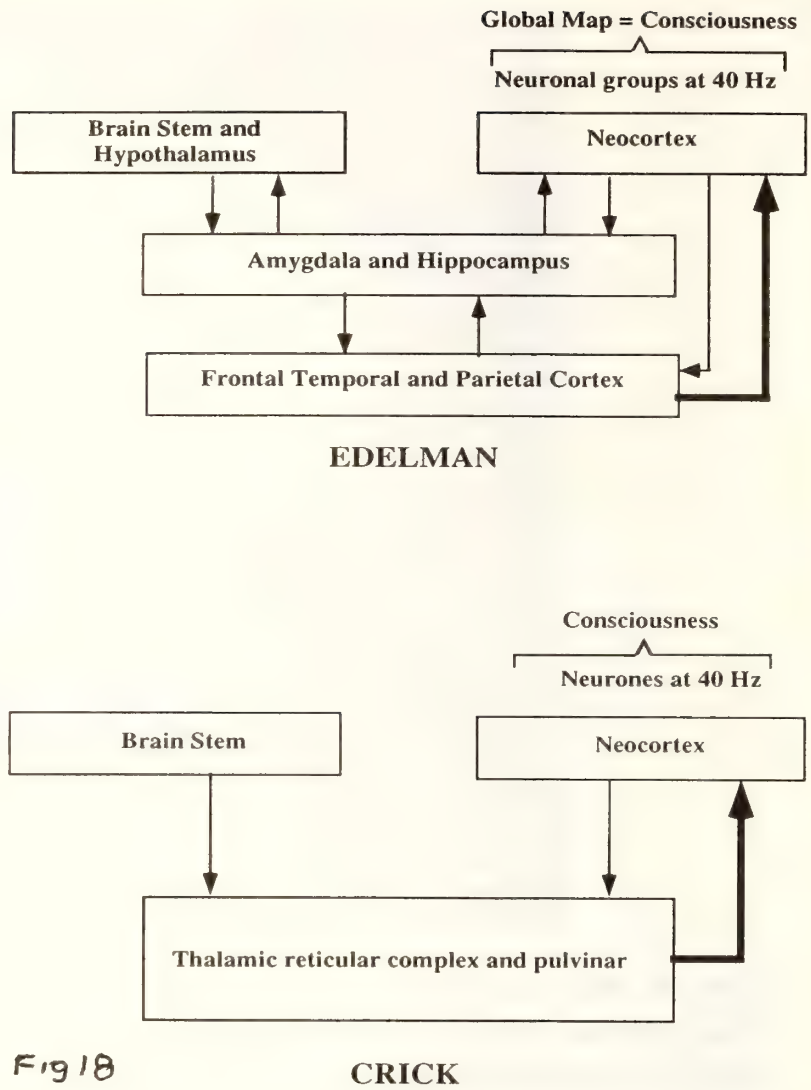

Fig 18

Figure 17. Evidence that brain stem neurones participate in the generation of 40 Hz oscillatory impulse firing in the neocortex. (A), shows twenty separate power spectra of electroencephalogram recordings taken from the neocortex (over a part called the suprasylvian gyrus); the frequency range about 40 Hz gives the maximum size waveform, indicating that most of the impulse firing cells are discharging at this frequency; the first ten records (from -10 to 0) are controls whereas the next ten records (from 0 to 10) are taken during stimulation of the brain stem parabrachial neurones, which increased the size of the 40 Hz oscillations. (B), shows another twenty recordings, taken under the same conditions as those in (A), but when the effects of transmitter release in the thalamus from the brain stem neurones is blocked with the drug scopolamine; in this case the 40 Hz oscillations are virtually wiped out in both the control condition (from -10 to 0) as well as during stimulation of the brain stem (from 0 to 10). Data from Steriade, Curro Dossi, Pare and Oakson, 1991.

Figure 18. Comparison of the ideas of Edelman and Crick for generating consciousness. In both cases consciousness consists of groups of neurones in the neocortex that have the same temporal firing properties at a particular moment in time, with emphasis placed on the phase matching of 40Hz oscillations. In the case of Crick, the choice of a particular group of neurones results from an interaction between the brain stem, thalamic reticular complex/pulvinar and the neocortex itself. In the case of Edelman a similar scheme is envisaged, but with more emphasis on the memory systems associated with emotional experiences (in the amygdala) and with declarative memory (in the hippocampus). The small arrow-heads indicate the direction of interaction between the different parts of the brain, with the large arrow-heads showing the final pathway for the selection of the neurones that give rise to consciousness.

noradrenaline, serotonin and acetylcholine respectively. Experimental evidence which shows that these pathways mediate the firing of the 40 Hz oscillations in the cortex associated with the solution of the binding problem and with attentional mechanisms is shown in Figure17. Electrodes are placed over a part of the neocortex in order to record the electroencephalogram (EEG); this gives a measure of the extent to which neurones are firing impulses at different frequencies in neocortex. Figure17 shows that frequencies at about 40 Hz are the most common and that the number of neurones that fire impulses at this rate (given by the amplitude of the 40 Hz waveform) is greatly increased following stimulation of the brainstem peribrachial neurones. If however the action of the transmitter released by these neurones (acetylcholine) is blocked (with the drug scopolamine) then the number of neurones that are firing in neocortex at 40 Hz is greatly decreased (Figure 17); stimulation of the peribrachial neurones now has no effect on the number of neocortical neurones firing at 40 Hz. Observations such as these for the other brainstem groups of neurones mentioned confirm that the control of the reticular complex and the pulvinar by the brainstem determines the gating process on the principal neurones of the thalamus. The brain stem then appears to have a major role in determining that the neocortex will possess neurones that are firing at 40 Hz. It would seem natural that this should be the case, as brain stem neurones are also involved in controlling the sleep-wake cycle, namely in determining the general extent of arousal of the neocortex. Although it is clear that the brain stem has a major excitatory effect on the gating mechanism in the thalamus, this is not to say that our attention is determined by the brain stem. There are more nerves projecting from the neocortex to the thalamus than from the thalamus to the neocortex (Figure13). It is very likely that the neocortical projections to the reticular complex and the pulvinar play a major role in determining which neurones in these areas will be activated and that the brain stem input ensures that the neurones so chosen are excited.

CONSCIOUSNESS AND GLOBAL MAP NEURONAL GROUPS.

Crick's idea, then, is that the thalamic reticular complex and the pulvinar interact with the brain stem and neocortical mechanisms to reach a salient decision as to which neuronal groups that are active will be brought into consciousness by the spotlight of attention Figure 18). Edelman has a rather similar notion of how consciousness arises. He refers to the neuronal groups that are participating in the synchronous 40 Hz firing as constituting a "global map" which at any particular time provides the content of what he refers to as primary consciousness. This "global map" is chosen by interaction with the emotional centres in the hypothalamus and brainstem through the hippocampus; these in turn interact with the frontal lobes, parietal cortex and temporal lobes to draw on the memory there laid down previously by the emotional emphasis given to previous "global maps" (Figure 18). These parts of neocortex then interact with the "global map neuronal groups" to settle on the final "global map". It is this map that constitutes consciousness. Edelman's mechanism of choosing the final "global map" is in principle the same as that suggested by Crick: neuronal groups in neocortex solve different binding problems but only a particular set of these is chosen by the spotlight of attention, to form the final global map. The difference between Crick and Edelman is in the details of what parts of the brain constitute the spotlight of attention. The important claim by both Crick and Edelman is, of course, that the final "global map neuronal groups" at any particular time constitute consciousness at that time.

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DISCUSSION OF 'LACHLAN AND NEW ENGLAND: FOLD BELTS OF CONTRASTING MAGMATIC AND TECTONIC DEVELOPMENT' BY B.W. CHAPPELL

C.M. GRAY

Chappell (1994) (*Journal and Proceedings of the Royal Society of New South Wales, 127, 47-59*) presents a review of the magmatic and tectonic development of the Lachlan and New England Orogenic Belts. The genetic model espoused for the granitic rocks in this, and numerous other publications, recognises fundamentally different S- and I-type granites, such that 'S-type granites were effectively derived exclusively from sedimentary material within the crust', and I-type granites formed 'by fractional melting of previously solidified mantle-derived material'.

The main alternative view to the Chappell model is that of Gray (1984, 1990), a postulate that granite genesis involved a crustally-derived component, a magma akin to the Cooma Granodiorite and formed by melting metasedimentary rocks, which interacts with basalt magma. In a discussion of the genesis of granitic rocks in the Lachlan Orogenic Belt (LOB) Chappell (1994) purports to disprove this hypothesis. Unfortunately, Chappell misconstrues significant parts of the Gray (1984) model and as a result his criticism is invalid.

Chappell (1994) reiterates the important observation that the Ca contents of typical Ordovician turbidites are distinctly lower than those of the majority of the LOB S-type granites, leading to the conclusion that these sedimentary rocks cannot have been the source material for the granites. The Gray (1984) hypothesis is then described in the following terms. 'Gray (1984) argued that .... the Lachlan granites result from mixing of basaltic material and granitic melt derived from the melting of Ordovician sedimentary rocks', and 'melt derived from the Ordovician sedimentary rocks, as postulated by Gray (1984)'. Criticism takes the form, 'Mixing of basalt with material derived from the Ordovician sedimentary rocks would increase the Ca, Na and Sr abundances as required, *although not necessarily by the appropriate amounts*' (my italics). These attributions to Gray (1984) are direct factual errors. Both papers by Gray (1984, 1990) were very carefully written to ensure that the source was not stated to be typical exposed Ordovician turbidite. However, when considering the Cooma Granodiorite as the crustal end member, Chappell (1994) compounds the error with the statement 'To make things even more difficult, it is now commonly accepted that the Cooma granite was not derived from typical Ordovician sedimentary rocks ...., but either from relatively feldspar-rich Ordovician material, or from unexposed older rocks of that character (Steele *et al.*, 1991)'. Rather, the actual source of Gray (1984) was the high grade metasedimentary rock of the Cooma Complex and not the low grade turbidites. Some of these gneisses have Ca contents distinctly higher than typical low grade turbidites and similar to those of the Cooma Granodiorite (Munksgaard, 1988). In addition, it was noted that the high grade rocks may have been carried from depth diapirically by the granodiorite (Flood and Vernon, 1978) and could be older than the low grade sequence. This is essentially the type of source proposed by Steele *et al.* (1991) and accepted by Chappell (1994). Melting of this source gave rise to the derivative crustal end member in the Gray (1984) hypothesis. For the purposes of simplifying the discussion in Gray (1984) the crustal end member was limited to material of Cooma type. However, the end member may vary in composition in response to change in the nature of the metasedimentary source. This is explicit in Gray (1984), 'The Cooma Granodiorite (72% SiO_2) will be taken as characteristic of meta-sedimentary-derived melts for the region recognising that this single pluton need not be perfectly representative'; the point was reiterated in Gray (1990). The exact meaning of the vague statement by Chappell (1994) italicised above concerning the inability of basalt mixing to generate the granite Ca, Na and Sr contents is unclear. However, part or all of this supposed difficulty can be accommodated by variation in source composition; it is hoped to discuss this issue at length elsewhere.

Chappell (1994) questions the involvement of basalt magmas in granite genesis in several ways. A further implication of the italicised statement above is that basalt compositions are incompatible with granite geochemical variation. The Gray (1984) model approached this issue using silica variation diagrams. To the author's knowledge of the published data for the Berridale, Kosciusko and Moruya Batholiths, all of

the granites with well-defined variation trends uninfluenced by fractionation can be projected to valid basaltic compositions; while this does not prove basalt involvement, it is consistent with it. It is true that exposed Palaeozoic basalt or gabbro is rare in the LOB and this may be a weakness of the basalt mixing model, but is not a fatal difficulty. Chappell (1994) is explicit in saying 'there is no direct evidence for the basalt end-member'.* This is incorrect. The variation diagrams for the I-type granites of the Kosciusko Batholith of Hine *et al.* (1978) include a gabbro from the region that is totally consistent with the Jindabyne I-type suite trends for virtually all analysed elements. Given the propensity of gabbros for fractionation and contamination that would induce scatter in variation trends, the agreement is startling. Hensen (*pers. comm., 1995*) has identified basaltic dykes in the Moruya Batholith with identical compositions to the distinctive basalt type predicted from granite variation diagrams; in this instance, the local basalt end member is available for inspection. The presence of mafic magma in the granite system (coexisting gabbroic diorite and tonalite magmas) is well-documented on a mesoscopic scale in the same batholith (Vernon *et al.*, 1988). Chappell (1994) also notes that 'metaluminous enclaves that could have been derived from ..... basaltic material are extremely rare in the mafic S-type granites'. However, if basalt-derived enclaves are partly hybridised or react with a peraluminous host magma, their metaluminous character will be lost. Fine grained, mafic, igneous-textured enclaves that could be the product, do occur in S-type granites.

A plot of normative corundum versus total FeO (Chappell, 1994) [or the equivalent aluminium saturation index (ASI defined as $Al_2O_3/CaO + Na_2O + K_2O$) versus total FeO (White and Chappell, 1988)] for the Bullenbalong S-type suite has a normative corundum (ASI) peak at intermediate FeO values (Fig. 1). The derivative statement by Chappell (1994) is, 'This is not consistent with the presence of a larger basaltic component in the more mafic rocks'. Such a statement should not have been left hanging as an apparent conclusion, for a legitimate interpretation of this diagram consistent with basalt mixing was enunciated by Gray (1990). This alternative interpretation is evident from Chappell's following discussion, but the proposition that mixing and fractionation are responsible is lost as the argument merges with another issue of the refractory nature of the source (see below), which also supposedly has a negative outcome for the Gray (1984) model. Recourse to this style of diagram necessitates comment on its properties - the ASI versus total FeO version will be used as it is more amenable to numerical treatment. Because the ASI is a compound ratio, two component mixing on an ASI versus total FeO diagram has an hyperbolic trajectory. Consider the case of mixing between a Bullenbalong sample of high ASI and basalt magma. The trajectory has a steep gradient from the Bullenbalong point curving towards the FeO axis with increasing FeO content (Fig. 1). In contrast, fractionation from the Bullenbalong sample to the quartz-feldspar assemblage of the granite minimum produces a curve in the opposite sense towards low ASI and FeO (Fig. 1). The combination of these two processes produces a peak on the ASI - FeO plot that comfortably accounts for the geometry of the Bullenbalong data array. Note that fractionation may affect any granite on the mixing curve so that fractionation is more accurately considered in terms of a family of curves towards the granite minimum. At the very least, the sample with the lowest total FeO (KB45) has the characteristics of a fractionated rock given its low CaO (1.26%) and Sr (65 ppm) contents. Given the likelihood of substantial fractionation the Bullenbalong suite is unsuited to any discussion of granite variation. The diagram for the Bullenbalong suite is difficult to assess completely because only 30 of 85 analyses used by White and Chappell (1988) have been published, though the complete data array can be found on their Figure 9. This data set does include numerous substantial plutons and can be regarded as important to the granite geochemistry of the LOB. However, as far as this author is aware using the data of White *et al.*

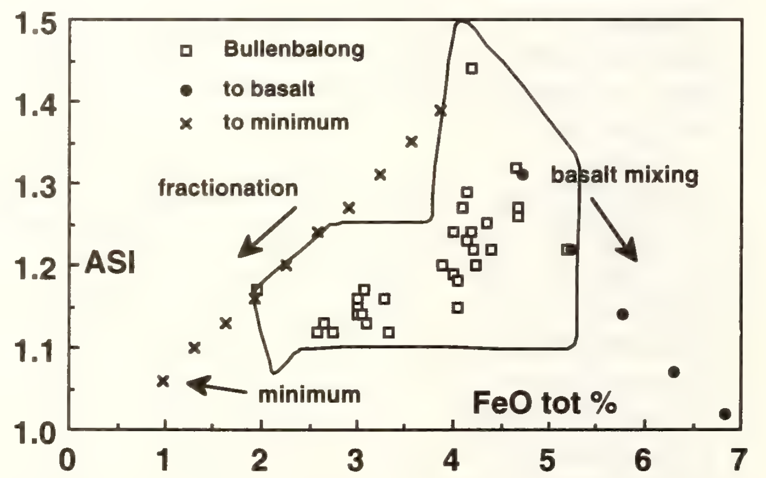

Figure 1: Aluminium saturation index (ASI - $Al_2O_3/CaO + Na_2O + K_2O$) versus total FeO percentage for granitic rocks of the Bullenbalong suite shown as open squares - data from White *et al.* (1977) and White and Chappell (1989). The field shown is for the complete Bullenbalong data of White and Chappell (1988). Calculated points that illustrate fractionation to a granite minimum composition (crosses to aplite BB72) and mixing to a basalt composition (solid circles to the Blind Gabbro which is located off the diagram) are anchored on the Bullenbalong point at highest ASI.

* Note that this is an invalid argument to question the Gray (1984) hypothesis because it applies equally well to the Chappell (1994) source regions for S- and I-type granites for which there is no direct evidence.

(1977) and White and Chappell (1989), the Bullenbalong suite is the solitary example in the Berridale and Kosciusko Batholiths that has a data array with an unequivocal intermediate ASI peak. For that reason alone it is dangerous for Chappell (1994) and White and Chappell (1988) to generalise from it, and its ASI diagram certainly does not disprove basalt mixing. All other suites are directly consistent with simple basalt mixing.

Chappell (1994) follows a further train of thought on the nature of the granitic end member that supposedly casts doubt on the Gray (1984) hypothesis. It appears to be presupposed that the end member (Cooma Granodiorite-like) must be a pure melt (i.e. no suspended crystals), hence the Cooma Granodiorite cannot be the end member, presumably because of its abundant suspended refractory minerals like cordierite. That being the case, the real Gray end member, being a true melt, has to have been an even more refractory composition and supposedly very difficult to produce. None of this has any relevance to the Gray (1984) model. The end member is explicitly stated to be a magma like the Cooma Granodiorite and any consideration of more refractory compositions is irrelevant. Ultimately, the details of the origin of the Cooma Granodiorite are unimportant to the model; all that is required is for it, or other purely metasedimentary-derived magmas, to exist, so that they can be the target for variable incorporation of basalt magma to generate a derivative spectrum of granites. As an aside, the words magma and melt were used synonymously in Gray (1984), in retrospect a loose usage that may have given rise to the Chappell (1994) concern about total melting.

The genetic model adopted for granitic rocks has significant input into tectonic interpretations of the LOB. The Chappell (1994) approach considers each distinct granite geochemical system to reflect a particular source region deep in the crust giving granites the capacity to directly 'image' the deep crust. The basalt mixing model ascribes a significant degree of granite geochemical variation to the type of basalt involved, greatly reducing the geochemical capacity to probe the crust; isotopic compositions then provide the more significant information (Gray, 1990).

The tectonic model of Chappell (1994) is dominated by the concept of 'deposition of the widespread Ordovician flysch sequence on continental-type crust, as required by the data for the S-type granites' (a derivative of the above argument concerning the chemical difference between the turbidites and the granites). This idea is at variance with the view of deposition of the turbidites on essentially oceanic crust (e.g. Cas *et al.*, 1980). There is also the muted suggestion that the source may have a Precambrian age (from White *et al.*, 1976), which has influenced tectonic models to the extent of postulation that Precambrian rocks have been underthrust into the belt (e.g. Crawford *et al.*, 1984). These conclusions are not automatic. It is worth considering the constraints on the age and affinities of the granite source. The argument for a Precambrian age (Compston and Chappell, 1979) applies to I-type granites and exploits the restite hypothesis overlain with geochemical calculation; the conclusion is very model-dependent. On the other hand, if the S-type granites formed by direct melting of the basement source (Chappell, 1994) their initial Sr isotopic compositions are inconsistent with Australian Precambrian metasedimentary successions (Gray, 1990). However, the literal interpretation of the ages of some inherited zircons in the granites as Early Palaeozoic (Williams, 1992) gives an unequivocal upper limit to the age of the source. As to the nature of the source, the pattern of inherited zircon ages in the granites is similar to that in the exposed turbidites (albeit the low-Ca turbidites which are not considered the granite source) (Chappell *et al.*, 1991). In terms of the complete Rb-Sr isotopic system (pseudo-isochron diagram) the granite trend in the eastern LOB is directed towards mean values for some of the turbidites (Gray, 1984, 1990). The conclusion here is that the granite source is undoubtedly Early Palaeozoic in age and there are several points that argue a *prima facie* link with some part of the turbidites. Accordingly, it is unnecessary to postulate a distinct crustal basement to the Ordovician sequence to act as the granite source, and this concept should not be a significant constraint on tectonic models. The basement may exist, but at present there is no evidence for it.

The second major tectonic issue is the nature of the heat source responsible for the extensive crustal melting evidenced by the granites. Chappell (1994) leaves this question unanswered. The basalt mixing model has an immediate explanation for the high geothermal gradient, namely the injection of basalt magma into the crust, though the trigger for this is unknown.

Let hypotheses contend. The basalt - crustal melt mixing model provides a relatively complete and internally consistent view of granite genesis and crustal structure.

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"ORE ELEMENTS IN ARC LAVAS" by R. L. Stanton

FORTY YEARS OF UNDERSTANDING THE GENESIS OF GREAT STRATIGRAPHIC OREBODIES OF THE WORLD

Reviewed by John C. Grover O.B.E.

Well known internationally, the author of numerous major papers and the text-book *ORE PETROLOGY* (which sold some 18,000 copies), Richard L. Stanton, formerly Professor of Geology at New England University, New South Wales, has recently produced a unique volume of value to practical mineral exploration and to university teaching.

Of 403 pages, and traditional hard cover, *ORE ELEMENTS IN ARC LAVAS* is Oxford Science Publication Monograph on Geology and Geophysics, Number 29.

If ever there were a labour of love (of science) this is it: the finale after forty years of thoughtful field work and laboratory research laced with adventure -- if one reads between the lines.

Beginning in the late 1940s with studies of conformable mineral deposits in New South Wales (Stanton, 1955a and b), in December 1950 Stanton was co-opted at short notice to join Professor Charles E. Marshall's Sydney University Geological Expedition and flown to the then British Solomon Islands Protectorate. It was to prove one of the most productive ventures of its day, to study what was geologically one of the least known regions of the world (Umbgrove 1945, p. 209; Glaessner 1950, p.870; Grover 1994, pp. 37-43).

Disappointed at having to cancel his arrangements for research during those summer holidays, Stanton was in no mood for the venture. He had no idea that he was about to see a grand picture in the rocks of those jungle-covered, roadless, volcanic mountains of islands rising from the Pacific -- where it rained heavily nearly every day and sometimes for days at a time. It did not halt his islanders, and the work continued on foot or by hired canoe, or launches whose engines too often failed to work. However, he was soon fired up with what he saw, taking the remoteness, the physical hardships and the administrative difficulties in his stride. Christmas Day he spent as an honoured guest in a small village of Santa Isabel watching the dancing prior to a feast of succulent pig cooked in a ground oven of hot stones.

Three months later he flew out to New Guinea and Australia. Stanton knew that his life had been changed by this visit (personal communication, 1951). Evidence stimulated his thoughts on stratiform metalliferous orebodies.

He later returned to the Solomon Islands with the support of the BSI Geological Survey Department. Visits by Stanton (and his colleague Dr P.J. Coleman, at different times) were to become annual events.

Welcomed at Honiara airport, after two nights as guest of the Geological Survey the visitor was then able to join the twin-screw 10.3 metre Geological Survey ship *Noula*, crewed, fuelled and supplied, with geological assistants and bearers ready to go -- all of them competent old hands quietly proud of their jobs. Shore work involved following and mapping many streams and rivers where outcrops were visible. Where the population was small and confined largely to the coast, inland areas were often trackless.

These expeditions considerably increased the knowledge of the Survey, for specimens and samples were air freighted to the university for study. Findings were published in due course. The contributions by Stanton and Coleman were on-going for years. In turn, Australian Universities developed a knowledge of island arc geology

which was previously lacking (Grover 1994, p.42).

Stanton's further studies at Queens University in North America embraced deposits at New Brunswick and in Newfoundland, and brought him into touch with other lively minds of the day, who gave him further encouragement.

In 1959, in company with Dr J.D. Bell of the Solomons Geological Survey, Stanton began investigating the Pliocene-to-Recent lavas of the New Georgia Group in the Solomons -- a wide spectrum of volcanics ranging from highly olivine-rich picritic lavas to felsic andesites. Suspicion that exhalative ores might have genetic ties with with lava differentiation stages led to the study of traces of the metals copper, zinc, lead, etc. It began in 1963 with wet chemical and x-ray fluorescence methods, but the techniques then were inadequate and the project was postponed for another decade or so -- after atomic absorption work by his long-time research assistant, Mrs W.P.H. Roberts, had shown that trace metals in the Solomon lavas occurred systematically and were probably amenable to geochemical investigations. Field work continued.

Interest led to a crescendo of scientific activity in the 1960s by the Royal Society, by private companies and by George P. Woollard and American Universities -- resulting in much geophysical documentation of this once least-known region of the world.

By 1980 automated and highly accurate X-ray fluorescence became available, along with the electron-probe microanalyser. The large collection of specimens from the previous three decades could be thus subjected to study.

Some 12,000 electron-microprobe analyses of mineral grains and glass in situ were made by Stanton, assisted by N.G. Ware of the Research School of Earth Sciences, Australian National University. 900 X-ray fluorescence, neutron activation and ICP-MS (inductively coupled plasma emission spectrometry/mass spectrometry) analyses of whole rock and mineral and groundmsss separations were made by Dr B. W. Chappell.

The results enshrined in this volume are set in the context of geochemistry from other island-arc lavas and mid-ocean ridges.

Previously little had been known of the behaviour of the principal ore minerals in lavas, and there was no systematic documentation of their incidence in the lavas of island arcs, the main locale of volcanic ores in ancient terrains. Yet the suggestion that some ores might have a volcanic origin had been made long ago (Beaumont. 1847; Bowen, 1933; Fenner, 1933). Their work had never been investigated. Clear statements of the theory began to emerge in the mid-1950s and this history of events is covered in the Introduction.

Chapters 2 to 4 give an outline of problems in volcanic ore petrology that led to the investigation and the historic connotations. Chapter 5 is more detailed, about the petrology and geochemistry of the Solomons lavas as a basis for the more detailed geochemical chapters.

Chapters 6 to 19 are concerned with the geochemistry and abundance behaviour of each of 14 elements in exhalative ores. The principal components, apart from iron and sulphur, are copper, zinc, lead, and barium. Strontium is next, though conspicuous by its absence from volcanic exhalative ores -- in spite of its close chemical relationship with barium, an eloquent clue to ore-forming processes. The remaining nine elements are dealt with in sequence of increasing atomic number.

Chapter 20 is about the behaviour of the hyperfusible elements sulphur, chlorine and fluorine, and minor metals silver, gold, molybdenum, cadmium and uranium; and the semi-metals arsenic, antimony and bismuth. It demonstrates some of the relationships between elements.

(a) abundances of potassium, rubidium, zirconium and strontium which indicate the melt process;

(b) minerals like barium, a trace constituent of lavas and also a major element of exhalative ores;

(c) ore elements, such as lead, which are important components of many ores associated with volcanic rocks, although their igneous systematics are not well known.

Data on the Solomons lavas have been given a frame of reference for the reader: early information from mid-ocean ridge

basalts is followed by island arc descriptions. Some arcs are fully oceanic, like Vanuatu, Tonga and the Solomons, which have no connection with continental crust. Other arcs do in part: like the Aleutians, the Lesser Antilles and the southern part of the Tonga-Kermadecs. Such information could have many uses as well as indicating areas needing more attention.

In Chapter 21 the information in the foregoing chapters is applied to examining the abundance patterns in a crystallising volcanic melt of Solomons island-arc type -- the Younger Volcanic suite.

Fractional crystallisation and loss of the volatile phase probably affected the enrichment and impoverishment of ore elements in melts. Leading from this, Chapter 22 is about volcanic sublimates, condensates, gases and plumes, Chapter 23 concerns the derivation and development of Solomons lavas, mainly the basalt-picrite and basalt-andesite-dacite lineages. Chapter 24 deals with the petrogenesis of exhalative ores in the light of all the features observed in the Solomon Islands Younger Volcanic Suite. This leads to relations between crystallisation, lava type, and reflections on the leaching hypothesis.

The account concludes with thoughts on ore-element geochemistry and the refining of mineral exploration methods in ancient island arc terrains, like those in Australia.

A purpose of the book has been to show how intimately and systematically some ore deposits are related to magmatic differentiation. It will serve to emphasise Crook's perceptiveness in 1914, and add substance to the past work of Lindgren, Fenner, Bower, Niggli and Buddington.

R. L. Stanton's *ORE ELEMENTS IN ARC LAVAS* is essential reading for university geology departments, geological surveys and for those engaged in major mineral search ventures

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Master of Science (Mathematics) Thesis Abstract: Dipole Modelling for the Localization of Human Visual Evoked Scalp Potential Sources

Monica K. Hurdal

One of the major goals of electrophysiology is the determination of sources of electrical activity in the human brain. Visual stimuli elicit visual evoked scalp potentials (VEPs) which can be recorded non-invasively as electroencephalograms (EEGs) by using scalp electrodes. This electrical activity is generated by electrical sources in the brain. A model of the head structure is required as well as a model of a source of electrical activity. Using this type of model, the location of electrical sources can be estimated.

The use of electrophysiological techniques, such as the standard 10-20 system of electrode placement and the use of brain scans as a further aid to VEP research are described, as is the anatomy of the visual cortex. The visual field appears to have a retinotopic mapping onto the visual cortex which can be represented by a cruciform model where the visual field locations project onto the opposite hemisphere of the primary visual cortex and the upper and lower fields project onto the lower and upper parts of the visual cortex respectively.

In this thesis, the forward problem, which is the prediction of a potential distribution due to a given electrical source, is examined. Various head models are reviewed and a three shell model which represents the head as three concentric spheres is used. The source of electrical activity is assumed to be a dipole. The forward problem is solved with this model and implemented practically with computer programs. Modifications involving rotations are applied to the model in order to accomplish this. These programs calculate a potential distribution on the surface of the scalp when given a single neural source. The radii of the spheres representing the head and their conductivities are incorporated into the model and a dipole source is described by six parameters which determine the position and orientation of the source. Topography maps are used to display the electrical potential distributions.

Subsequently, the inverse problem, which is to determine a dipole source that is the best generator of a given potential distribution, is solved in the least squares sense. The same model is used as in the forward problem. As the calculation of the potential is nonlinear in three of the six parameters, various minimization search algorithms are discussed. A computational procedure which uses the Levenberg-Marquardt method for nonlinear least squares is implemented and determines the best dipole source by varying the six parameters associated with the dipole's position, orientation and strength. Predictions of the potentials at the electrode sites which are closest to the observed potentials in the least squares sense are obtained. The dipole at this point is thought of as the source of the observed EEG activity.

When solving the inverse problem, the choice of electric potential reference site should not affect the location of the dipole source. A new method is presented which adds an additional parameter, a constant, to the model that is to be estimated along with the six dipole parameters. This method accounts for variations in the reference site of the observed potential data so an estimated dipole source is not affected by the reference site. Confidence intervals involving the model parameters are also calculated and help determine the validity of the dipole solution. Testing has revealed that quick convergence rates of the dipole solution, high signal to noise ratios in the EEG data, small confidence interval ranges for the estimated parameters, and similar observed and predicted results help to indicate the validity of a dipole solution.

The computer implementation of the inverse problem is then applied to visual evoked potential data obtained from two experiments. In this manner, dipole source localization is applied to experimental findings as a data analysis technique. The first experiment uses a checkerboard pattern reversal stimulus and the second uses a pattern onset stimulus and data is analyzed for two subjects in both experiments. Both experiments also use magnetic resonance imaging (MRI) scans of the subjects' heads to determine if morphological differences between subjects contribute towards individual differences in the VEPs.

Results from the checkerboard pattern onset experiment using dipole source localization revealed that stimuli in the left visual field generated sources in the right hemisphere of the brain. The sources due to upper visual field stimuli localized lower in the visual cortex than did the sources which were caused by stimuli in the lower visual field. In addition, the sources due to the peak positive and negative latency in a cyclic waveform from the same stimulus condition were located in the same position but had opposite orientations, indicating a polarity reversal. These results conform to the cruciform model. However, as the stimulus moved from the upper visual field to the lower visual field, a polarity reversal was only seen in some of the stimulus conditions. As stimulus eccentricity increased, the dipole sources due to the upper visual field stimuli moved deeper into the cortical tissue, but this was more difficult to see in the lower visual field sources.

Results from the pattern onset experiment did reveal a polarity reversal as the stimulus moved from upper to lower visual fields. It was expected that the first component would be striate related. Three peak components were observed, but no conclusions could be made about the origin of the source for the evoked potential response. There was a large variability in the VEPs between subjects. The MRI scans revealed large variability in the calcarine fissures between subjects as well. The dipole localization of the VEPs in conjunction with the MRI scans indicated that the large individual variability between subjects could be explained by anatomical differences in the occipital lobe rather than functional differences.

Thus, dipole source modelling for the localization of human visual evoked potential sources is examined in this thesis. Dipole analysis results of the two experiments in conjunction with magnetic resonance images and electrical potential topography maps help to indicate how anatomical differences in the brain may play a role in individual variability. These experiments demonstrate that dipole source localization has a practical place in analyzing visual evoked potential data. Dipole modelling is a useful and effective tool for the localization of human visual evoked potentials.

This research has been presented at two conferences which will have their proceedings published (Hurdal, McElwain and Finlay, 1995; Hurdal, McElwain and Finlay, in press) as well as a third conference (Hurdal, unpublished). A paper including the dipole source localization method is in submission for publication (Hurdal, McElwain and Finlay, in submission). A paper incorporating results from one of the visual evoked potential studies has been published (Chorlton, Hurdal, Fulham, Finlay and McElwain, 1994) and another VEP paper which uses dipole source localization is also in submission (Hurdal, Fulham, McElwain and Finlay, in submission).

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Hurdal, M. K., McElwain, D. L. S. and Finlay, D. C. (1995), Dipole source localization of human visually evoked scalp potentials, pp. 192--193 *in* Liebert, B., Ward, P. B. and Michie, P., *Biological Psychology*, **39**, Abstracts of papers presented at the Third Annual Conference of the Australian Society for Psychophysiology, 187--202. Presented at the 1993 Australasian Conference on Psychophysiology.

Hurdal, M. K., McElwain, D. L. S. and Finlay, D. C. (in submission), Dipole source localization: Confidence intervals and reference-free modelling, *IEEE Transactions on Biomedical Engineering*.

Hurdal, M. K., McElwain, D. L. S. and Finlay, D. C. (in press), Dipole source estimation: The localization of visually evoked potential sources, *Brain Topography*. Presented at the 1994 Pan Pacific Conference on Brain Electric Topography.

Hurdal, M. K., Fulham, W. R., McElwain, D. L. S. and Finlay, D. C. (in submission), Localization of brain activity associated with pattern reversal VEPs

using the equivalent dipole technique, *Electroencephalography and Clinical Neurophysiology*.

Thesis was submitted for the Degree of Master of Science in the Department of Mathematics, University of Newcastle, 1994.

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DOCTORAL THESIS ABSTRACT

Doctoral Thesis Abstract: Population dynamics of *Steinernema carpocapsae* and *Heterorhabditis bacteriophora* in *in vivo* and *in vitro* culture

JINXIAN WANG

The population development of *Heterorhabditis bacteriophora* and *Steinernema carpocapsae* has been studied in larvae of the greater wax moth, *Galleria mellonella*, after being initiated from a single reproductive individual. The insect host was used to establish an optimal standard for fecundity with which to compare the fecundity obtained in *in vitro* culture.

Studies of the population dynamics of *H. bacteriophora* and *S. carpocapsae* in *in vitro* solid culture showed that inoculum size is important for optimising the final yields of infective juveniles, and the time in which these are achieved. The highest yield for *H. bacteriophora* was found with an inoculum of one million infective juveniles per flask which was ten fold the optimal inoculum for *S. carpocapsae*. Studies on the populations of these nematodes derived from the extremes of high and low inocula (one or two infective juveniles to ten million infective juveniles per flask) also provided interesting information on the population development of the nematodes. The significance of these findings for commercial mass production are discussed.

In liquid culture, varying inoculum sizes of *S. carpocapsae* was shown to have a greater effect on the population development and the final yields of infective juveniles than in solid culture, particularly with lower levels of inocula. Liquid culture required much larger inocula, and the nematodes did not reproduce when the inoculum was low. The effects of shear force from agitation for oxygenation in, and other factors involved with, *in vitro* monoxenic liquid culture are also discussed. The relationship between the populations of *S. carpocapsae* and its symbiotic bacterium, *Xenorhabdus nematophilus*, was investigated and the symbiotic bacterium populations were shown to be influenced by the population development of the nematode.

The present study also demonstrated the separate effects of different levels of oxygen and carbon dioxide on the population development and final yields of *S. carpocapsae*. Lowering oxygen levels resulted in slower population development and reduced final yields of infective juveniles. Negligible or no increase of nematode populations was found with oxygen levels below 2%. In contrast, the higher the carbon dioxide levels, the lower the nematode yields, with yields in 10% CO_2 being little more than half, and in 20% CO_2 being only about one thirtieth, the yields in air. These findings have significant bearing on optimising yields of infective juveniles in the mass production of entomopathogenic nematodes.

Preliminary studies were made on the possibility that pheromones affect the formation and recovery of the infective juveniles of *S. carpocapsae*. Despite a variety of experiments with culture supernatant and solvent extracts of cultures, no positive results were achieved. Further investigations are needed to finally determine the existence and effect of such pheromones.

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Ph.D. Thesis Abstract:

OPTIMIZATION ALGORITHMS ON HOMOGENEOUS SPACES: WITH APPLICATIONS IN LINEAR SYSTEMS THEORY.

ROBERT MAHONY

Constrained optimization problems are commonplace in linear systems theory. In many cases the constraint set is a homogeneous space and the additional geometric insight provided by the Lie-group structure provides a framework in which to tackle the numerical optimization task. The fundamental advantage of this approach is that algorithms designed and implemented using the geometry of the homogeneous space explicitly preserve the constraint set.

In this thesis the numerical solution of a number of optimization problems constrained to homogeneous spaces are considered. The first example studied is the task of determining the eigenvalues of a symmetric matrix (or the singular values of an arbitrary matrix) by interpolating known gradient flow solutions using matrix exponentials. Next the related problem of determining principal components of a synmmetric matrix is discussed. A continuous-time gradient flow is derived that leads to a discrete exponential interpolation of the continuous-time flow which converges to the desired limit. A comparison to classical algorithms for the same task is given. The third example discussed, this time drawn from the field of linear systems theory, is the task of arbitrary pole placement using static feedback for a structured class of linear systems.

The remainder of the thesis provides a review of the underlying theory relevant to the three examples considered and develops a mathematical framework in which the proposed numerical algorithms can be understood. This framework leads to a general form for a solution to any optimization problem on a homogeneous space. An important consequence of the theoretical review is that it develops the mathematical tools necessary to understand more sophisticated numerical algorithms. The thesis concludes by proposing a quadratically convergent numerical optimization method, based on the Newton-Raphson algorithm, which evolves explicitly on a Lie-group.

KEYWORDS: Constrained optimization, Lie groups, Homogeneous spaces, Symmetric eigenvalue problem, Linear systems theory, Steepest ascent method, Newton-Raphson method.

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Doctoral Thesis Abstract

Wood Digestion in *Panesthia cribrata*

Andrew M. Scrivener

The Australian cockroach *Panesthia cribrata* lives in and feeds on rotting *Eucalyptus* spp. logs. All of the carbohydrates in the wood diet were digested by the cockroach to some extent; lignin was not digested. Carbohydrase activities in the gut were generally appropriate to the diet. Endo-β-1,4-glucanase (EC 3.2.1.4), β-glucosidase (EC 3.2.1.21), endo-β-1,4-xylanase (EC 3.2.1.8), α-amylase (EC 3.2.1.1), maltase (EC 3.2.1.20) and sucrase (EC 3.2.1.48) activities were similarly distributed in the gut, with more than 90% of each activity in the foregut and midgut.

The cellulase of *P. cribrata* is endogenous and consists of two major (EG1 and EG2) and at least four minor endo-β-1,4-glucanase components and one major (GD1) and one minor (GD2) β-glucosidase component. EG1 and EG2 were purified by molecular sieve and ion exchange chromatography and had molecular weights of 53,600 and 48,800, respectively. With carboxymethylcellulose (CMC) the K_m, V_{max} and k_{cat} for EG1 were 9.4 mg/ml, 22.2 mg reducing sugar/min/mg protein and 20.0 s^{-1}, respectively; corresponding values for EG2 were 6.8, 88.3 and 64.2. Values for K_m, V_{max} and k_{cat} were also calculated for activity against cellotetraose and cellopentaose; neither EG1 or EG2 hydrolysed cellobiose or cellotriose. Relative activities of EG1 and EG2 against CMC and crystalline cellulose were 5200: 1 and 3500: 1, respectively. EG1 and EG2 constituted approximately 13% of the protein in the foregut and midgut contents. It is proposed that the inefficiency of EG1 and EG2 against crystalline cellulose is compensated for by their presence in large amounts in the gut. Four minor components (EG3 - 6) contributed between 4 and 10% of the gut endo-β-1,4-glucanase activity.

The β-glucosidase components GD1 and GD2 were partially purified. Values for K_m and V_{max} with cellodextrins from cellobiose to cellopentaose and *p*-nitrophenyl-β-D-glucopyranoside were estimated for GD1 and GD2; neither component hydrolysed CMC or crystalline cellulose. GD1 was competitively inhibited by glucono-δ-1,5-lactone (K_i = 0.33 mM), but was not inhibited by glucose at physiological concentrations.

P. cribrata inhabit wood extensively degraded by fungi; the contribution of fungal cellulase to cellulose digestion in *P. cribrata* was investigated. Minor cockroach and fungal endo-β-1,4-glucanase components co-eluted on Bio-Gel A-0.5 m; minor *P. cribrata* components were shown to be endogenous as they were present in salivary gland and midgut epithelium extracts and extracts from cockroaches maintained on cellulose and starch. Fungal cellulase was not present in the gut, did not

synergise with cockroach cellulase and did not contribute to cellulose digestion in *P. cribrata*. Fungi are not required to convert crystalline into amorphous cellulose as both were hydrolysed at similar rates by cockroach gut extracts. It is concluded that fungi soften the wood, facilitating burrowing by the cockroach.

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DOCTORAL THESIS ABSTRACT

THE DEVELOPMENT OF MUTATION DETECTION TECHNIQUES AND THEIR APPLICATION TO DISEASE DIAGNOSIS

Andrea M. Douglas, B.Sc.(Hons.)

Advances in the polymerase chain reaction (PCR) have been responsible for much of the progress in human genetics that has taken place of late. The development of PCR has revolutionised the methods available for the detection of DNA mutations at the molecular level. The purpose of this research was to assess specific PCR mutation detection techniques, to test the efficiency of existing protocols, and improve upon these where necessary. In addition, to allow the ultimate analysis of mutation detection, a more practical sequencing protocol for PCR products than those currently available was to be developed.

The cytochrome P450 IID6 enzyme is responsible for the metabolism of at least 25 drugs, resulting in two distinct phenotypes in the population, the extensive (EM) and poor (PM) metabolisers. The identification of the mutant alleles causing the PM phenotype allows the genetic testing of individuals via DNA based assays. This study tested the efficiency of existing PCR screening procedures in both clinical and forensic samples. Previously used PCR/RFLP based techniques were assessed with regard to the detection of the three major inactivating mutations in the CYP2D6 gene. These methods were found to be limiting, either because of the lack of controls for restriction enzyme digestion, or because of the need for multiple rounds of PCR. These detection methods were therefore modified to include a site-specific PCR method which resulted in the analysis of all the mutations in a single PCR. This simpler PCR method was successful in accurately predicting phenotype in 88 % of individuals. When individuals were homozygous for two mutant alleles or two wild-type alleles present at either locus the accuracy was 96 %. Furthermore, when individuals were heterozygous for both of the *CYP2D6(A)* and *(B)* alleles it was discovered that phenotyping was more complex, requiring familial analyses.

A simple, multiplex method was also developed for the direct sequencing of PCR products, superior to previously described protocols. Sequencing reactions were performed directly on PCR products without the need for purification of the template by removal of residual deoxyribonucleoside triphosphates and primers. The coupling of a chemiluminescent detection system with the use of the same primers in the initial and sequencing PCRs allowed the sequencing of a number of PCR fragments on the one gel.

In the course of extending this direct sequencing protocol to PCR products greater than 1 kilobase, it was found that the sequencing procedure was more efficient if smaller PCR fragments were amplified and then multiplexed. In addition, during the process of optimising these larger PCR systems, it was demonstrated that degradation of PCR products occurs in the 94 °C denaturation step of the cycling. Thus, the denaturation time is now considered a variable that needs to be optimised with any new PCR system.

An analysis of the entire apolipoprotein AI gene resulting in the detection of previously unknown point mutations demonstrated the reliability of this sequencing method to search for point mutations in a defined region of DNA. Furthermore, the variation of gel loading of sequencing samples employed in this study resulted in the detection of new mutations in a more efficient manner.

A thesis submitted for the degree of Doctor of Philosophy in the Department of Forensic Medicine, Monash University, July 1994.

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Doctoral Thesis Abstract

Development of Metal Chelates as Potential Probes of DNA Structure

Susan E. Kidd

A series of ruthenium(II) complexes containing the N_4-tetradentate ligand *N,N'*-bis(2-picolyl)-1,2-diaminocyclohexane (picchxn) has been synthesised. The complex products showed a predisposition for the tetradentate to coordinate in a *cis*-ß structural arrangement to the metal ion. Only in one case did the ligand coordinate to form a *cis*-α complex. With the isolation of Λ-$ß_2$-[Ru(*RR*-picchxn)-(dmso)Cl]$ClO_4.2H_2O$ and Δ-$ß_n$-[Ru(*RR*-picchxn)-(dmso)Cl]$ClO_4.3.5H_2O$ and their enantiomers (n is either 1 or 2) it is shown that the interaction of Ru(II) and picchxn is neither truly stereo- nor enantiospecific.

On reaction of the enantiomeric $ß_2$ forms with the amino acids (aa), *S*-alanine or *S*-tryptophan, the complexes Λ-(or Δ-)ß-[Ru(*RR*-(or *SS*-)picchxnmi)(aa)]$^+$ were formed. Here the coordinated tetradentate was found to undergo a photo-oxidative dehydrogenation reaction to form a monoimine (picchxnmi) with the amino acid not being oxidised. The isolation of Λ-$ß_2$-[Ru(*RR*-picchxnmi)(dmso)Cl]$ClO_4.0.5H_2O$ suggested that this photo-oxidative reaction was not an isolated occurrence for the amino acid complexes only.

All products were characterised by a combination of microanalysis, electronic absorption, nuclear magnetic resonance and circular dichroism spectroscopic methods.

Both enantiomeric forms of the $ß_2$ and $ß_n$ species were observed to interact with calf-thymus DNA. The proposed interaction for these complexes is one of covalent binding which is found to be photoinduced. The amino acid complexes under photo-controlled conditions, are not labile and do not show any major form of interaction with calf-thymus DNA.

To further develop complexes to act as spectroscopic probes of nucleic acid structure via intercalation into DNA, the $ß_2$-dmso-Cl enantiomeric complexes were reacted with a number of bidentate ligands based upon substituted 1,10-phenanthroline or *o*-phenylenediamine. During these reactions the picchxn ligand remained stereospecific in its coordination to the central metal ion. Again the tetradentate in these complexes was shown to be susceptible to photo-oxidative dehydrogenation to form the monoimine. One such complex, Λ-ß-[Ru(*RR*-picchxnmi)(phen)]$(ClO_4)_2$.phen.3.5H_2O was found to cocrystallise with an unbound phen molecule, and containing both phens in a stacking arrangement. These non-labile bidentates prevented covalent binding of the Ru(picchxn)$^{2+}$ moiety to DNA.

Intercalation of the phen based complexes was concluded if their visible absorption spectra showed a red shift and hypochromicity when combined with DNA in aqueous solution. The complexes containing phen, dip, dppz or $dppzMe_2$ are proposed to behave in this manner. The metal complex with the most potential for use as a chiral probe of DNA is thought to be ß-[Ru(picchxnmi)-(dip)]$^{2+}$, with its Λ enantiomer showing a 95% preference when interacting with calf-thymus DNA. Lower preferences were determined for the racemic diamine and monoimine phen species although again their Λ enantiomers are preferred.

An abstract from the thesis submitted to Macquarie University for the degree of Doctor of Philosophy, March 1994.

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Annual Report of Council

for the year ended 31st March 1995

PATRON

The Council wishes to express its gratitude to his Excellency Rear Admiral Peter Sinclair, AC Governor of New South Wales, for his continuing support as Patron of the Society.

MEETINGS

Eight General Monthly Meetings and the 127th Annual General Meeting were held during the year. The Annual General Meeting and seven of the General Monthly Meetings were held at the Australian Museum. A summary of proceedings is set out below.

Special meeting and events in 1994/95:-

February 14th, 1995 (AGL Centre, North Sydney)
The Society was co-sponsor of a joint meeting with four societies: The Australian Institute of Energy (Sydney); the Australian Nuclear Association; The Nuclear Engineering Panel and the Institution of Engineers, Australia (Sydney).
Dr. K.M. Sullivan spoke on:- "Energy and Climate:- An Update".

March 15th, 1995
The Society's Annual Dinner was held at the Holme and Sutherland Room, University of Sydney Union Reception Centre. The Guest of Honour was the Lord Mayor of Sydney, Mr. Frank Sartor, who presented an address concerning the significance of the forthcoming Olympic Games in Sydney.

Meetings of Council:
Eleven Meetings of Council were held at the Society's Offices at North Ryde. The average attendance was 13.

April, 29th, 1994 (at Kurnell, Sydney):-
The President, Mr. John Hardie, and the Hon. Secretary Ed., Mrs Krysko v. Tryst, accepted an invitation to represent the Society at the ceremony to commemorate the landing of Captain Cook on 29 April 1770.

June 23rd, 1994
Mrs. Shirley Sinclair, wife of His Excellency Rear Admiral Peter Sinclair, A.C. Governor of New South Wales and Patron of the Society visited the Rooms of the Society at North Ryde. Mrs. Sinclair was accompanied by her Secretary, Miss Jacqueline Chaulker. Mrs. Sinclair was welcomed by the Hon. Librarian, Miss Pat Callaghan, the Hon. Secretary (Editorial), Mrs. M. Krysko v. Tryst, and by the office Secretary, Mrs. V. Chandler.

After inspecting the Rooms and activities Mrs. Sinclair took afternoon tea.

July 30th, 1994 (at History House, Sydney)
The Society was a co-sponsor of a joint meeting with ANZAAS NSW and in co-operation with the Colonial Science Club on `Achievements of European Scientists and Engineers in Australia'. Four addresses were delivered during the half day seminar:-

1. Dr. Jan Todd (Research School of Social Sciences ANU) on Contributions from Pasteur Institute's Overseas Branch in Sydney.

2. Mrs. Uta von Homeyer (Faculty of Social Science, Flinders University, S.A.) and
3. Emeritus Prof. H.K. Messerle FTS (University of Sydney) discussed Achievements by German Scientists and Engineers during the early post war period.

4. Prof. P. Fritz (University of Technology, Sydney) on "Contributions by Scientists and Engineers from Eastern European countries.

August 9th, 1995 (at the University of New South Wales
The 29th Liversidge Research Lecture for 1994 was delivered by Prof. Ian G. Dance (Dept. of Inorganic Chemistry, University of New South Wales) on "Inorganic Chemistry:-Frontiers and Future.

PUBLICATIONS

Volume 127, Parts 1,2,3 and 4 of the <u>Journal and Proceedings</u> were published during the year. They incorporated nine papers including the 47th Clarke Memorial Lecture for 1993, an address by

His Excellency Rear Admiral Peter Sinclair, AC., Governor of New South Wales and Patron of the Society at the Annual Dinner 1994 and the Presidential address for 1994. Twelve abstracts of post graduate theses were also published in this volume as well as the Annual Report of Council for 1993-94. Council wishes to thank all the voluntary referees who assessed papers offered for publication. Nine issues of the Bulletin (No. 176-184) were published during the year, and Council thanks the authors of short articles for their contribution.

Council granted permission to reproduce material from the Journal and Proceedings in several instances.

AWARDS

The following awards were made for 1994:-

JAMES COOK MEDAL (for outstanding contributions to science and human welfare in and for the Southern Hemisphere):-
Sir Gustav Nossal, AC,CBE,FRS,FAA, Director of the Walter and Eliza Hall Institute of Medical Research, Melbourne Vic.

CLARKE MEDAL (in Botany):-
Joint award: Dr. Barbara Gillian Briggs, Senior Assistant Director (Scientific) Royal Botanic Gardens, Sydney NSW.
and Prof. Craig Anthony Atkins, D.Sc., Dept. of Botany, University of Western Australia.

EDGEWORTH DAVID MEDAL (research worker under 35 years of age):-
A/Professor Richard Hume Middleton Ph.D., Dept. of Electrical and Computer Engineering, University of Newcastle, N.S.W.

THE SOCIETY'S MEDAL (for scientific research and services to the Society):-
Dr. Edmund Clarence Potter, Kariong N.S.W.

ARCHIBALD D. OLLE PRIZE (best paper published by a member in the Society's Journal):-
Mr. Michael Organ, B.Sc., Archivist University of Wollongong N.S.W.

The Walter Burfitt was not awarded for 1994.

MEMBERSHIP

The membership of the Society at 31st March 1995 was:-

Patron	1
Honorary Members	16
Members	265
Associates, Spouse members	20
Total:	302

During the year Emeritus Professor John M. Bennett, AO, and Professor Donald H. Napper, FAA, were elected Honorary Members.

The deaths of the following members were announced with regret:-

Mr Kenneth John BROWN, on 13 July, 1994.
Mr Beverly CORTIS-JONES, on 12 June, 1994.
Dr John Allan DULHUNTY, on 7 April, 1994.
Miss Dorothy Jean ELLISON, on 5 October, 1994.
Dr Robert Mortimer GASCOIGNE, on 3 April, 1994.
Mr Kenneth Roderick GLASSON, on 27 November, 1994.
Mr Norman Frederick HALL, on 13 June 1994.
Dr Harvey Donald Robert MALCOLM, on 18 March, 1994.
Professor Simon James PROKHOVNIC, on 20 June 1994.
Dr Phyllis Margaret ROUNTREE, on 27 July, 1994.
Sir Frederick WHITE (Honorary Member), on 17 August, 1994.

OFFICE

The Society continued during the year to lease for its office and Library a half share of Convocation House, 134 Herring Road, North Ryde, on the southeastern edge of the Macquarie University Campus. The Council is grateful to the University for allowing it to continue leasing the premises. Council greatly appreciates the secretarial assistance rendered by Mrs. V. Chandler during the past year.

SUMMER SCHOOL

As in previous years the Summer School for 1995 (16-20 January 1995) was successfully conducted. The venue was Macquarie University.

54 students were enrolled from 11 private high schools and 21 state high schools within the State of New South Wales. Among the country centres who took part in the Summer School were Broken Hill, Tumbarumba, Walgett, Gunnedah and Moree and others. Fifteen voluntary speakers from private, government and academic institutions responded to Council's invitation to address the students during the week-

long activities. Two half-day excursions were carried out, both of them to private industrial enterprises. These excursions play a vital part as they provide industrial insight and contact with persons working in the particular field covered by the Summer School. One visit was made to Burns Philp Research and Development (Food and Fermentation Division), the other to Colby Engineering (Design and Manufacture of Packaging Systems for the International Dairy Powder Industry world-wide). Council thanks both establishments for their generous co-operation.

Council of the Society also wishes to thank the voluntary speakers and organisers of the visits whose well presented addresses and demonstrations greatly contributed to the success of the Summer School.

Council's appreciation is extended to Mrs. Krysko, Dr. Coenraads and to the various Council Members who assisted and chaired sessions as well as to Mrs. W.C.H. Swaine and Mrs. Nancy Sutherland.

The Official Opening was undertaken by Mrs. Shirley Sinclair, wife of His Excellency Rear Admiral Peter Sinclair, A.C. Governor of New South Wales and Patron of the Royal Society of New South Wales. Council offers its thanks to Mrs. Sinclair.

Also taking part in the Official Opening were the President of the Society, Mr. John Hardie, Mr. Andrew A. Tink, M.P., Member of the Council of Macquarie University, and Prof. J.A. Piper representing the Vice-Chancellor Emeritus Professor Di Yerbury AM, of Macquarie University.

LIBRARY REPORT FOR 1994/1995

As in previous years, acquisition by gift and exchange has been maintained. The relevant lists of journals and other publications received in this way have been monitored to accommodate any changes that may have occurred. Material from overseas and some Australian material are sent directly to the Dixson Library at the University of New England, other Australian material is held in the Society's Office at North Ryde.

The Council thanks Mr Karl Schmude, University Librarian, University of New England, for his continuing efficient care and responsibility in maintaining the processing and availability of the Royal Society Collection in the Dixson Library.

In January 1995, the Hon. Librarian Miss Patricia M. Callaghan, & the President (1994/5) of the Society, Mr John R. Hardie, visited the Dixson Library at the invitation of Mr Schmude. The visit included a guided tour of the Dixson Library and its special collections. The Royal Society Collection is housed in a special room where a notice gives details of the history of the Society. However, some serials have been used to complete, or add to the Dixson Serials Collection. Each item of the Royal Society Collection is identifiable by a logo on the spine (of the book) and a well designed book plate.

The Catalogue of the Royal Society, Dixson Library, University of New England is a subject catalogue in classified (Dewey) order, published in book-form. It was suggested that a complementary author/title catalogue would be useful.

Mr Schmude had arranged a luncheon at a town restaurant where we were joined by Em. Professor R.L. Stanton of the University of New England, and a member of the New England Branch of the Society. A very interesting and pleasant day - "a happy occasion", as Professor Stanton described it.

SOUTHERN HIGHLANDS BRANCH REPORT

The Inaugural Meeting of this Branch was held on Sunday 19th June 1994 at Oxley College. 24 people were present including the President, Mr. John Hardie (who addressed the Meeting), Dr. Alan Day and Dr. R. Bhathal, Mrs. Jane Lemann was elected Branch Chair-person, Roger Ware Branch Vice Chair-person, Dr. Kelvin Grose Branch Honorary Secretary, Mr. Martin Lemann Branch Honorary Treasurer, Mr. Roy Perry Branch Publicity Officer and Mr. Roger Ware Branch Newsletter Editor. Dr. Kelvin Grose represents the Branch on the Council of the Royal Society of New South Wales.

Friday 15th July 1994
On this day Dr. Kelvin Grose located the grave of Dr. Henry Grattan Douglass at St. John's Anglican Church, Camden. Dr. Douglass was one of the founders of the Philosophical Society of Australasia which ultimately became the Royal Society of New South Wales. Dr. Grose reported to his own Branch and to Council that the grave is in need of renovation.

Wednesday, 27th July 1994
Dr Ken McCracken delivered an address which he entitled "Reminiscences of a

Space Scientist", illustrated by hardware in the form of actual pieces of satellites and photographs taken from satellites. The meeting was held at Bowral Golf Club where 32 members and visitors sat down to dinner with Dr McCracken. The evening was voted an outstanding success. A vote of thanks was proposed by Dr Phillip Knowles.

Thursday, 6 October 1994
Dr Armstrong Osborne gave a slide presentation and address entitled "Tales from Marble Halls: Reading the Rocks at Wombeyan Caves". 40 members and visitors were present at Links House for the talk and 30 afterwards sat down to an excellent dinner with Dr Osborne. Commander David Robertson proposed a vote of thanks to the lecturer.

October 1994: A sum of $200 (Trust Fund) was received from Mr. Douqlass Baglin of Mudgee towards the restoration of Dr Douglass's grave.

October 1994: Dr Kelvin Grose located Mrs Barbara King, a descendant of Dr Douglass. Mrs King's brother, Edgar Beale, was a well-known figure in the Illawarra district for many years (he died in 1989). Solicitor, historian, promoter of the University College which ultimately became the University of Wollongong, Edgar's special interest was history and particularly the history of Australian exploration. He wrote eight books, and four of these were devoted to the explorers Kennedy and Charles Sturt. On his death he left behind the manuscript of another book on Sturt.

Friday, 11 November 1994
A function was held at St Anne's Anglican Church, Ryde in honour of Ann Rumsby and Dr H.G. Douglass. The President, Mr. John Hardie, the Hon. Librarian Miss Pat Callaghan and the Hon. Secretary (Editorial) Mrs. M. Krysko attended. The President, John Hardie, welcomed everyone and Dr Kelvin Grose explained how Dr Douglass and his wife, Hester, brought Ann Rumsby and her husband, William Bragge, together (both are buried in the churchyard where the function was held). Mrs Berenice Campbell of Wahroonga and her sister Sybil (Great Great Grand-daughters of Ann and William) assembled at least a dozen representatives of the Bragge family. Present also were Miss Barbara King and her son Rory McGuire. Mrs King is the Great Great Grand-daughter of Dr Douglass.

Thursday, 24 November 1994
Professor F.O. Stephens gave his talk on "New Approaches with Integrated Treatment of Locally Advanced Cancers" at Bowral Golf Club, 30 members and visitors were present including six members of the medical profession. 24 members and guests sat down to dinner with Professor Stephens. Martin Lemann proposed the vote of thanks.

NEW ENGLAND BRANCH REPORT

The Branch held the following meetings during 1994:

Tuesday, 21st June 1994:- Professor Aubrey Egan of the Cattle and Beef Industry Co-operative Research Centre in Armidale spoke on "What is Meat Research?". The speaker provided the following abstract:-

"Meat has been an important component of the human diet throughout recorded history. Consumption is now increasing in countries with rising living standards as diets change and consumers move towards "Western" foods. In contrast, consumption in developed countries with traditionally high per capita levels is now falling.

Meat is a major commodity in world trade and Australia is a leading exporter. Currently exports are valued at $3 billion with about half of our beef production going overseas. Overall, the industry is internationally competitive, but is facing major challenges especially in the processing sector. Meeting market specifications for quality and consistency and satisfying increasingly demanding consumer requirements are major issues.

The talk will cover the properties of meat and factors affecting its quality. Research issues will be identified and current Australian research activities described.

Members and visitors attended the meeting which was held in the Main (Somerville) Lecture Theatre, Department of Physics, University of New England, Armidale.

Wednesday, 26th October 1994:- Professor Bruce G. Thom, Vice-Chancellor of the University of New England spoke on "Coastal Environmental Change and Coastal Policy". He supplied the following notes:-

"Of increasing concern to the community are pressures being placed by development on the natural heritage of the coastal zone. There are those who seek economic gain from the use of natural resources as well as those who see the need to conserve fragile ecosystems.

There are also those who aspire to a life style of relaxation (and retirement) close to the sea, but with comforts that put pressure on the use of space within the coastal zone especially through the demand and disposal of water. Government agencies are forced to plan for a future which in New South Wales and southern Queensland will embrace a doubling of population by the year 2020.

Consideration of matters of conflict in the use of coastal land must be understood in the context of past, present and future knowledge of coastal environmental change. There are several scales at which change can be evaluated. The natural inheritance from period of rising to stable sea levels provides a scale which embraces sediment transport to form the major coastal features as we know them. However, human activities and global forces (eg. enhanced green house effect) are now stimulating further changes which can regionally and locally threaten plans for use of coastal lands.

Members and visitors attended the meeting in the Main (Somerville) Lecture Theatre, Department of Physics, University of New England, Armidale.

ABSTRACT OF PROCEEDINGS

6 April, 1994

(a) The 1040th General Monthly Meeting was held at the Australian Museum, Sydney. The President, Dr. R.A.L. Osborne, was in the Chair and 20 members and visitors were present.

(b) The 127th Annual General Meeting. Same location. The President, Dr. R.A.L. Osborne was in the Chair, and 20 members and visitors were present. The Annual Report of Council for 1993-94 and the Financial Report for 1993 were adopted; Messrs. Wylie and Puttock were elected Auditors for 1994.

The following Awards for 1993 were announced:-

Clarke Medal (Zoology):-
Professor Gordon Clifford Grigg
Edgeworth David Medal:-
Dr. John Howard Scerritt
The Royal Society of New South Wales Medal:-
Dr. Harold George Royal

These Awards had been presented by His Excellency Rear Admiral Peter Sinclair AC, on the occasion of the Annual Dinner on March 22nd, 1994.

The Walter Burfitt Prize, the Archibald D. Olle Prize and the Cook Medal were not awarded this year.

The following Office-Bearers and Council Members were elected for 1994/1995:

President:	Mr. J.R. Hardie
Vice-Presidents:	Dr R.A.L. Osborne
	Dr. F.L. Sutherland
	Professor J.H. Loxton
	Dr. E.C. Potter
	Dr. D.J. Swaine
Honorary Treasurer:	Assoc/Prof D.E. Winch
Honorary Librarian:	Miss P.M. Callaghan
Honorary Secretaries:	Mrs. M. Krysko v. Tryst
	Mr. G.W.K. Ford
Members of Council:	Dr. R.S. Bhathal
	Dr. D.F. Branagan
	Dr. A.A. Day
	Dr. G.C. Lowenthal
	Assoc/Prof. W.E. Smith
New England Representative:	Professor S.C. Haydon

The retiring President, Dr. Armstrong Osborne, who had Chaired both the Meetings to this point, yielded the Chair to the incoming President, Mr. John Hardie.

Dr. Osborne presented his presidential address: "Caves, Cement, Bats & Tourists: Karst Science & Limestone Resource Management in Australia". A vote of thanks was proposed by Dr. F.L. Sutherland.

May 4th, 1994

The 1041st General Monthly Meeting was held in the Australian Museum, Sydney. The President Mr. J.R. Hardie was in the Chair and 26 members and visitors were present.

Mr. W. Hudson-Shaw addressed the meeting on "Lawrence Hargrave - The Forgotton Man". A vote of thanks was proposed by Dr. R.S. Bhathal.

June 1st, 1994

The 1042nd General Monthly Meeting was held at the Australian Museum, Sydney. The President, Mr. J.R. Hardie was in the Chair and 22 members and visitors attended. Mr. K.W. Riley from the Div. of Coal and Energy Technology, CSIRO, presented an address "Fogs,

Fossil Fuels and the Fall from Grace of St. Mary's Purgatory Stone". The vote of thanks was offered by Dr. D.F. Branagan.

July 6th, 1994

The 1043rd General Monthly Meeting was held at the Australian Museum, Sydney. The President Mr. J.R. Hardie was in the Chair and 43 members and visitors were present. Professor John M. Brooke of the Department of History, Lancaster University, U.K. gave an address entitled "The Earth Sciences and their Cultural Implications: The Question of Religious Belief".

Dr. A.A. Day proposed a vote of thanks. This meeting was held jointly with the 19th International Congress on the History of The Geological Sciences, Sydney.

Council announced that a new branch The Southern Highlands Branch of the Royal Society of New South Wales was formed and its inaugural meeting took place on 19th June, 1994 in Bowral N.S.W.

August 3rd, 1994

The 1044th General Monthly Meeting was held at the Australian Museum, Sydney. The President Mr. J.R. Hardie was in the Chair and 19 members and visitors were present.

Dr. Robert A. Creelman gave an address entitled "Hunter Valley Salinity". Dr. F.L. Sutherland proposed a vote of thanks.

September 7th, 1994

The 1045th General Monthly Meeting was held at the Australian Museum, Sydney. The President Mr. J.R. Hardie was in the Chair and 33 members and visitors were present.

Dr. Robert Coenraads addressed the Meeting on "The Stone Statues of Easter Island: A Secret in their Making". The vote of thanks was proposed by Dr. E.C. Potter.

October 5th, 1994

The 1046th General Monthly Meeting took place at the Australian Museum, Sydney. The President Mr. J.R. Hardie was in the Chair and 14 members and visitors attended.

Professor Frederick O. Stephens AM, University of Sydney and Royal Prince Alfred Melanoma Unit, gave an address on "Critical Review of Recently Published Cancer Cures". The President Mr J.R. Hardie, proposed a vote of thanks.

November 2nd, 1994

The 1047th General Monthly Meeting was held at the University of Western Sydney, Macarthur. The President Mr. J.R. Hardie was in the Chair and 47 members and visitors attended.

A/Professor Roger Alexander, Dean of the Faculty of Business and Technology, University of Western Sydney, Macarther, addressed the Meeting on "Integrated Commerce and Science Education". Professor W.J. Vagg, the Foundation Dean of the Faculty and a member of the Society, proposed a vote of thanks.

Participants in the Summer School on "Science in Food Technology" 16-20 January, 1994, held at Macquarie University.

Members of Council of the Royal Society of New South Wales:-
Front row: extreme left: Miss P.M. Callaghan, Hon. Librarian,
extreme right: Mrs. M. Krysko v. Tryst, Hon. Secretary (Editorial) and Hon. Convener of the Summer School.
2nd row: from front: at extreme left: Mr. J.R. Hardie, President,
2nd from right: Prof. D.J. Swaine, Vice-President.

THE ROYAL SOCIETY OF NEW SOUTH WALES

AUDITORS REPORT TO THE MEMBERS

Scope

We have audited the financial statements, contained on pages 2 to 11 of The Royal Society of New South Wales for the year ended 31 December 1994. We have conducted an independent audit of these financial statements in order to express an opinion on them to the members of the society.

Our audit has been conducted in accordance with Australian Auditing Standards to provide reasonable assurance as to whether the financial statements are free of material misstatement. Our procedures included examination, on a test basis, of evidence supporting the amounts and other disclosures in the financial statements, and the evaluation of accounting policies and significant accounting estimates. These procedures have been undertaken to form an opinion as to whether, in all material respects, the financial statements are presented fairly in accordance with Australian accounting standards so as to present a view of the society which is consistent with our understanding of its financial position and the results of its operations and cash flows.

The audit opinion expressed in this report has been formed on the above basis.

Audit Opinion

In our opinion the financial statements of The Royal Society of New South Wales are properly drawn up:

(a) so as to give a true and fair view of the state of affairs of the society at 31 December 1994 and of the results and cash flows of the society for the year ended on that date; and

(b) in accordance with applicable Accounting Standards.

WYLIE & PUTTOCK
Chartered Accountants
ALAN M PUTTOCK

189 Kent Street
SYDNEY NSW 2000

THE ROYAL SOCIETY OF NEW SOUTH WALES

BALANCE SHEET AT 31 DECEMBER 1994

1993		NOTE	1994
	CURRENT ASSETS		
5454	Cash	2	3685
4093	Receivables	3	3945
0	Investments		0
0	Inventories		0
1479	Other	4	1505
11026	TOTAL CURRENT ASSETS		9135
	NON-CURRENT ASSETS		
0	Receivables		0
146485	Investments	5	139146
0	Inventories		0
18049	Property, plant and equipment	6	17225
0	Intangibles		0
0	Other		0
164534	TOTAL NON-CURRENT ASSETS		156371
175560	TOTAL ASSETS		165506
	CURRENT LIABILITIES		
7607	Creditors and borrowings	7	3392
0	Provisions		0
1421	Other	8	1954
9028	TOTAL CURRENT LIABILITIES		5346
	NON-CURRENT LIABILITIES		
0	Creditors and borrowings		0
0	Provisions		0
103	Other	8	86
103	TOTAL NON-CURRENT LIABILITIES		86
9131	TOTAL LIABILITIES		5432
166429	NET ASSETS		160074

THE ROYAL SOCIETY OF NEW SOUTH WALES

BALANCE SHEET AT 31 DECEMBER 1994 - (Cont.)

1993		NOTE	1994
	EQUITY		
7311	Library reserve	9	7311
9494	Library fund	10	9928
21854	Trust funds	11	21973
127770	Other accumulated funds		120862
166429	TOTAL EQUITY		160074
	Capital and leasing commitments	16	
	Contingent liabilities	17	

J R HARDIE President D E WINCH Honorary Treasurer

ACCUMULATED FUNDS ACCOUNT

For the year ended 31 December 1994

1993		NOTE	1994
(5692)	Operating surplus (deficit)		(6908)
647	Donations and interest to library fund	10	434
2000	Bequest		0
(3045)			(6474)
130211	Accumulated funds at the beginning of the financial year		127770
1251	Transferred from library fund	10	0
128417			121296
647	Transferred to library fund	10	434
127770	Accumulated funds at end of the financial year		120862

The accompanying notes form part of these financial statements

THE ROYAL SOCIETY OF NEW SOUTH WALES

STATEMENT OF CASH FLOWS

For the year ended 31 December 1994

1993		NOTE	1994
	CASH FLOWS FROM OPERATING ACTIVITIES		
7735	Members subscriptions and donations		8485
11433	Other revenue sources		17195
7180	Interest received		4725
(31010)	Administration and other operating expenses		(39513)
(4662)	Net cash provided by (used in) operating activities	18	(9108)
	CASH FLOWS FROM INVESTING ACTIVITIES		
4945	Net reduction in investments		7339
4945	Net cash provided by investing activities		7339
283	NET INCREASE (DECREASE) IN CASH HELD		(1769)
5171	Cash at the beginning of the financial year		5454
5454	CASH AT THE END OF THE FINANCIAL YEAR		3685

The accompanying notes form part of this statement of cash flows

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1994

1 STATEMENT OF ACCOUNTING POLICIES

The accounts have been prepared in accordance with applicable Accounting Standards. The accounts have also been prepared on the basis of historical costs and do not take into account changing money values or, except where stated, current valuations of non-current assets. Cost is based on the fair values of the consideration given in exchange for assets. The accounting policies have been consistently applied, unless otherwise stated.

The following is a summary ofthe significant accountingpolicies adopted by the societyin the preparation of the accounts.

(a) Non-Current Investments

Investments are brought to account at cost. The carrying amount of investments is reviewed annually to ensure it is not in excess of the recoverable amount of the investments.

(b) Property, Plant & Equipment

Property, plant and equipment are brought to account at cost or at independent valuation, less, where applicable, any accumulated depreciation or amortisation. The carrying amount of property, plant and equipment is reviewed annually to ensure it is not in excess of the recoverable amount from these assets.

The depreciable amount of all fixed assets is depreciated over their useful lives commencing from the time the asset is held ready for use.

The exception to the above policy is the society's library which is brought to account at its 1936 independent valuation, a more recent valuation not being available.

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1994

1 STATEMENT OF ACCOUNTING POLICIES - (Cont.)

(c) Unearned Revenue

The unearned revenue shown in the accounts will be brought to account in the next financial year.

(d) Comparative Figures

Where required by Accounting Standards comparative figures have been adjusted to conform with changes in presentation for the current financial year.

1993		1994
	2 CASH	
	Included in cash are:	
23	Cash on hand	0
5431	Cash at bank	3685
5454		3685
	3 RECEIVABLES	
	Included in Current Receivables are:	
2128	Debtors for subscriptions	3408
2128	Less provision for doubtful debts	3408
0		0
4093	Debtors for contributions towards printing Journal and Proceedings	1731
0	Other debtors	2214
4093		3945

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1994

1993		1994
	4 OTHER ASSETS	
	Included in Current Other Assets are:	
1479	Prepayments	1505
==========		==========
	5 INVESTMENTS	
	Included in Non-Current Investments are:	
146485	Interest bearing deposits	139146
==========		==========
	6 PROPERTY PLANT AND EQUIPMENT	
	Included in Property, Plant & Equipment are:	
674	Office equipment and furniture - at cost less depreciation	603
3765	Office equipment - at 1991 valuation less depreciation	3012
13600	Library - at 1936 valuation	13600
10	Pictures - at cost less depreciation	10
----------		----------
18049		17225
==========		==========
	7 CREDITORS AND BORROWINGS	
	Included in Current Creditors & Borrowings are:	
6607	Creditors and accruals re Journal and Proceedings printing and distribution	0
50	Other creditors and accruals	152
950	Unearned revenue	3240
----------		----------
7607		3392
==========		==========

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1994

1993		1994
	8 OTHER LIABILITIES	
	Included in Current Other Liabilities are:	
16	Life members subscriptions prepaid	16
283	Membership subscriptions paid in advance	286
1122	Journal and Proceedings subscriptions paid in advance	1652
----------		----------
1421		1954
==========		==========
	Included in Non-Current Other Liabilities are:	
103	Life members subscriptions prepaid	87
==========		==========
	9 LIBRARY RESERVE	
7311	Balance at 1 January	7311
0	Movement for year	0
----------		----------
7311	Balance at 31 December	7311
==========		==========
	10 LIBRARY FUND	
10098	Balance at 1 January	9494
647	Donations and interest	434
----------		----------
10745		9928
----------		----------
251	Library purchases and expenses	0
1000	Contribution towards printing Journal and Proceedings	0
----------		----------
1251		0
----------		----------
9494	Balance at 31 December	9928
==========		==========

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1994

1993		1994
	11 TRUST FUNDS	
	Included in Trust Funds are:	
3917	Clarke Memorial Fund	3585
6514	Walter Burfitt Prize Fund	6657
3837	Liversidge Bequest Fund	3954
7586	Olle Bequest Fund	7777
21854		21973
	12 CLARKE MEMORIAL FUND	
5000	Capital	5000
	Revenue	
249	Income for year	238
220	Expenditure for year	570
29	Surplus (deficit) for year	(332)
(1112)	Balance at 1 January	(1083)
(1083)	Balance at 31 December	(1415)
3917	Total fund capital and revenue	3585
	13 WALTER BURFITT PRIZE FUND	
3000	Capital	3000
	Revenue	
150	Income for year	143
1169	Expenditure for year	0
(1019)	Surplus (deficit) for year	143
4533	Balance at 1 January	3514
3514	Balance at 31 December	3657
6514	Total fund capital and revenue	6657

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1994

1993		1994
	14 LIVERSIDGE BEQUEST FUND	
3000	Capital	3000
	Revenue	
150	Income for year	143
498	Expenditure for year	26
(348)	Surplus (deficit) for year	117
1185	Balance at 1 January	837
837	Balance at 31 December	954
3837	Total fund capital and revenue	3954
	15 OLLE BEQUEST FUND	
4000	Capital	4000
	Revenue	
199	Income for year	191
0	Expenditure for year	0
199	Surplus (deficit) for year	191
3387	Balance at 1 January	3586
3586	Balance at 31 December	3777
7586	Total fund capital and revenue	7777
	16 CAPITAL AND LEASING COMMITMENTS	
0	Capital and leasing expenditure commitments contracted for but not already included in the balance sheet	0

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1994

1993		1994
	17 CONTINGENT LIABILITIES	
	NIL	
	18 CASH FLOW INFORMATION	
	Reconciliation of net cash provided by operating activities to operating surplus (deficit)	
(5692)	Operating surplus (deficit)	(6908)
2000	Bequest	0
647	Library fund donations & interest	434
	Non-cash flows in operating surplus	1130
	Depreciation	824
	Changes in assets and liabilities	
(2247)	Reduction (increase) in receivables	148
442	Reduction (increase) in prepayments	(26)
(5990)	Increase (reduction) in unearned revenue	2290
6657	Increase (reduction) in creditors	(6505)
103	Increase in members subscriptions in advance	(14)
(573)	Increase (reduction) in journal subscriptions in advance	530
(1139)	Reduction (increase) in trust funds	119
(4662)	Net cash provided by (used in) operating activities	9108

THE ROYAL SOCIETY OF NEW SOUTH WALES

DETAILED INCOME AND EXPENDITURE ACCOUNT
For the year ended 31 December 1994

1993		1994
	INCOME	
8173	Membership Subscriptions	9897
45	Application Fees	306
8218		10203
8744	Subscriptions and Contributions to Journal Publication Costs	6154
16962	Total Membership and Journal Income	16357
6241	Interest Received	6100
235	Sale of Reprints	551
1105	Sale of Back Numbers	2403
20	Sale of Other Publications	213
10	Research Fees	0
0	Donations - General	26
3537	Summer School Surplus	0
0	Annual Dinner Surplus	60
0	Other Income	101
28110		25811
	Less EXPENSES	
2310	Accountancy Fees	2500
490	Advertising	0
118	Annual Dinner Deficit	0
1190	Audit Fees	1300
67	Bank Charges & Government Duties	82
0	Branches of the Society	200
350	Computer Software	0
1130	Depreciation	824
240	Entertainment Expenses	538
617	Insurance	618
14009	Journal Publication & Distribution Costs	10782
251	Library Expenses	0
38	Miscellaneous Expenses	850
297	Monthly Meeting Expenses	314
2382	Newsletter Printing & Distribution	2129
569	Postage	655
736	Printing & Stationery	865
1057	Provision for Doubtful Debts	1732

DETAILED INCOME AND EXPENDITURE ACCOUNT - (Cont)
For the year ended 31 December 1994

1993		1994
2000	Rent	2000
0	Repairs	78
5151	Salaries	5603
210	Secretarial Services	0
0	Summer School Deficit	1312
220	Superannuation Contributions	0
370	Telephone	337
33802		32719
(5692)	DEFICIT for the year	(6908)

AWARDS

CLARKE MEDAL FOR 1994
(Joint Award)

Professor Craig Anthony Atkins is Professor in the Department of Botany, University of Western Australia. He studied at the Farrer Memorial Agricultural High School in Tamworth, New South Wales, before going on to higher studies at the University of Sydney. Here he gained a MSc Agr. in 1966, and went on to Queens University, Kingston, Canada, where he was awarded a PhD in 1969. He returned to Australia as a Post Doctoral Fellow, working in the Plant Physiology Unit CSIRO, the Botany Department, University of Sydney and the Department of Biology, Macquarie University. Further overseas experience as a Research Scientist at the International Atomic Energy Agency, Vienna, Austria, was followed by appointment as Lecturer in the Department of Botany, University of Western Australia in 1974. His progress at that institution was capped by an award of DSc in 1983 and appointment as Professor in 1986.

In his scientific field, Professor Atkins is distinguished for his unique contributions to facets of the cellular locations or purine metabolism in legumes. In early collaborative work, Professor Atkins helped establish the carbon and nitrogen economics of the grain legume-module of symbiosis. He then independently discovered that proplastids of infected cells are the major sites of purine synthesis. His work is characterised by experiments that use all the advances of chemical, biochemical and molecular technology. His current collaborative work on genetic manipulation of pod abortion in grain legumes has fundamental and practical importance.

Professor Atkins has an outstanding record in administrative avenues and in gaining grant funds for scientific projects. He has extensive connection with and is an adviser to many institutions and government agencies. He serves on the editorial boards of several international journals and has been an invited lecturer to many meetings and organisations.

For his most distinguished record in his research on legumes and in services to both academic and agricultural organisations, Professor Atkins is a most worthy recipient for the award of the Clark Medal in Botany for 1994.

FLS

Dr Barbara Gillian Briggs has greatly enhanced the work of the Royal Botanic Gardens in Sydney, where she is presently Senior Assistant Director (Scientific). From Hornsby Girls High School, she proceeded to higher studies at the University of Sydney where she gained 1st Class Honours in 1956 and a PhD in 1961. After taking a CSIRO overseas scholarship at the University of California, Berkeley, she was appointed a Botanist at the Royal Botanic Gardens in 1967. From here she developed her studies of major Australian botanic groups, placing these groups in a world perspective and achieving international status for her work.

Dr Briggs was one of the first Australian botanists to consider evolutionary relationships between taxa in the context of plant migration, plate tectonics and geological history. Her studies include: examination of chromosome numbers and morphology; ecological and reproductive barriers to gene flow; evolution of inflorescence structure; interrelationships of higher level taxa; and cladistic analyses of morphology and DNA sequences at generic and family levels. Particularly important are her investigations of the three great Southern plant families the Myrtacaea, Proteaceae and Restionaceae.

Dr Briggs is an active administrator in the scientific role of the Royal Botanic Gardens, which has become the premier institute for taxonomic botany in Australia. She has encouraged the development of scientific expertise in her institution and assisted funding for this scientific work, such as the advance in phycological studies. She has facilitated and contributed to the

"Flora of New South Wales", a major publication of four volumes. She has been President and Councillor of the Linnean Society of New South Wales, and has participated in the work of several overseas professional bodies that promote biological studies.

Dr Barbara Briggs has continued the scientific spirit of the Reverend W.B. Clarke more than a century later and is a worthy recipient of the Clarke Medal in Botany for 1994.

FLS

THE JAMES COOK MEDAL FOR 1994

The James Cook Medal for "outstanding contributions to science and human welfare in and for the Southern Hemisphere" is awarded to Sir Gustav Nossal, AC, CBE, FRS, FAA, Director of The Walter and Eliza Hall Institute of Medical Research.

Sir Gustav was born in Bad Ischl, Austria, and came to Australia in 1939. He gained his primary degrees in Medicine at The University of Sydney, and his PhD from the University of Melbourne. Apart from a few years overseas at Stanford University, at the Pasteur Institute and as a Special Consultant to the WHO, all Nossal's research has been done at The Hall Institute. He was made an Honorary Member of our Society in 1986.

Sir Gustav Nossal has made major contributions to the fields of antibody formation and immunological tolerance. His research has required the use of novel and technically difficult micromanipulation techniques which, for example, enabled studies to be done on antibody formation by single cells. The discovery that one cell always made one antibody specificity was fundamental to the understanding of the immune system. Amongst his other major discoveries are in the field of lymphoid cells, namely, T cells and B cells, and in bone marrow differentiation, where definite proof was established that bone marrow is the factory for B lymphocytes. Nossal's work on the nature of immunological tolerance has led to the development of a new theory, called the clonal anergy theory. As well as his own research, Nossal has collaborated with several other scientists and their work exemplifies the importance of the team approach to research.

Sir Gustav Nossal has written 5 books and published more than 400 papers and he has received a host of honours from about 10 countries. He is a foreign Associate of the US National Academy of Sciences, a Member of the Academie des Sciences of France, and the recipient of the Albert Einstein World Award of Science, the Emil von Behring Prize and the Rabbi Shai Shacknai Prize. His involvement with internationl health is maintained by his chairmanship of the WHO Committee on the Global Program on Vaccines. There is no doubt that Sir Gustav Nossal is an outstanding scientist. His work and that of his team have established world leadership by dint of innovative and experimentally-challenging research. There are few Australian scientists who have achieved such eminence. It is surely fitting that Sir Gustav Nossal joins the select group of recipients of The Cook Medal.

DJS

EDGEWORTH DAVID MEDAL FOR 1994

The Edgeworth David Medal, for distinguished contributions to Australian science by a young scientist under the age of 35 years old, is awarded to Richard Hume Middleton, *BSc, BE (Hons), PhD, Newcastle.*

Richard Middleton studied Electrical Engineering at the University of Newcastle where he obtained first class honours and a University Medal in 1983 and the Doctor of Philosophy in 1985 with a thesis on *Modern continuous and discrete control.* He was appointed to a Lectureship at the University of Newcastle in 1986 and rose rapidly to the rank of Associate Professor in 1993. He is currently Head of the Department of Electrical and Computer Engineering and Associate Director of the Centre for Industrial Control Science at the University of Newcastle.

Richard Middleton has held major grants from the Australian Research Council since 1988 for such projects

as 'Analysis and design of robust control systems' and 'Electrical energy generation and storage using small-to-medium sized wind-powered turbines.' He won the outstanding young investigator award of the Australian Telecommunications and Electronics Research Board in 1991.

His research interests are in microprocessor systems and control, power electronics and satellite tracking systems. He has written a well-known text book on *Digital Control and Estimation* and 22 papers in international refereed journals as well as a number of short communications and conference presentations. He has developed sophisticated signal processing algorithms which are being used commercially to track satellites at locations in a number of countries.

Richard Middleton has made widespread contributions to the theory and practice of Electrical Engineering in Australia and is a worthy recipient of the Edgeworth David Medal.

JHL

THE ROYAL SOCIETY OF NEW SOUTH WALES MEDAL FOR 1994

This Medal for achievements in science and for the advancement of the Society is awarded to Dr Edmund Clarence Potter.

Dr. Potter graduated in chemistry from London University in 1944 and took his PhD in electrochemistry at Imperial College. Then followed the publication of a well-regarded book, entitled "Electrochemistry - Principles and Applications". His early research on metallic corrosion established him as a prime worker in various aspects of corrosion and he is still frequently consulted for informed statements on certain corrosion problems.

In 1968 he joined the CSIRO at North Ryde where his relevant electrochemistry background was used to investigate several aspects of the electrostatic precipitation of flyash particles from the combustion of coal for power generation. His studies, involving bench-scale experiments related to the full-scale situation, helped to shed light on this important matter. His experimental work is characterised by a certain flair for innovation. Dr. Potter retired from CSIRO as a Chief Research Scientist. He had also been very active in the CSIRO Officers' Association, especially as President.

Dr. Potter's research has been mainly in applied science and the results of his work are embodied in about 70 papers and 4 patents. In 1956 he received a Beilby Memorial Award for advances in power-station chemistry and in 1982 he was awarded the Corrosion Medal of the Australasian Corrosion Association. He is a Fellow of the Royal Society of Chemistry and of the Royal Australian Chemical Institute. He has established a dual international reputation in his two main research fields. He has shown a proper appreciation of the key role of analytical chemistry in most chemical research projects, something not commonly appreciated nowadays.

Although he has specialised in the fields of corrosion and electrostatic precipitation, Edmund Potter is keenly interested in science in the broadest sense, including historical aspects. He is a very active bushwalker where his powers of observation often detect interesting details.

Since retiring from CSIRO in 1988, Edmund Potter has been an enthusiastic and effective member of our Society. He is always there when extra tasks have to be performed and these he does with much-appreciated good humour. He has been a member of the Council since 1989 as a Vice-President and as President in 1991-1992. Edmund Potter's contributions to science and to our Society strongly endorse this award of the Society's Medal.

DJS

ARCHIBALD D. OLLE PRIZE FOR 1994

The Archibald D. Olle Prize is awarded from time to time at the discretion of the Council to the member of the Society who in any year submits to the Society the best treatise, or writing, or paper on any subject coming within the province of the Society for that year.

The prize is awarded to Mr. Michael Organ, BSc, for his paper entitled 'Bibliography of the Reverend W.B. Clarke (1798-1878): "Father of Australian Geology", published in the Journal and Proceedings, Volume 127, part 3. The Reverend Clarke was one of the founders of this Society during the second half of last century, and a comprehensive bibliography of his many works has been long wanting. As early as 1879, the year following Clarke's death, the then president of the Society, Professor John Smith, bemoaned the absence of such a listing.

Mr. Organ, a member of the Society, obtained an Honours degree majoring in geology from the University of Wollongong in 1986 and has been a long-time student of the Reverend Clarke. A paper on Clarke was recently published in the Historical Records of Australian Science, whilst Mr. Organ has also been involved in collaborative projects on coal geology of the Sydney Basin and igneous petrology at Wollongong University. He is also a keen historian (Secretary of the Illawarra Historical Society), with a number of publications on Aboriginal history.

The Clarke bibliography was begun in 1987 and has received input from fellow students of the history of Australian earth sciences, including the late Prof. T.G. Vallance, Ann Moyal, and David Williams of the Bureau of Meteorology.

Mr. Organ is at present employed as Archivist at the University of Wollongong, after having worked as a Research Assistant in various departments at that institution since 1989. His current research interests include the history of the development of the oil shale industry in New South Wales during the late 1860s and the visit of an Austrian scientific expedition to Sydney in 1858 aboard the Imperial Frigate Novara.

Report on Presentation of the Clarke Medal for 1992

Recipient:
Professor Alfred Edward Ringwood (see Vol. 126 Parts 1 and 2, p 105 for citation).

Professor D.H. Green of the Research School of Earth Sciences Institute of Advanced Studies, Australian National University, Canberra ACT, kindly arranged the presentation and reported as follows:-

"The Clarke Medal of the Royal Society of New South Wales was accepted by Mr Peter Ringwood on behalf of his father, the late Professor A.E. Ringwood, FAA, FRS. The medal was presented by Professor Ken Campbell representing the Royal Society of New South Wales and the presentation took place on Friday, 20 May in the Director's Office, Research School of Earth Sciences. The presentation was attended by members of Professor Ringwood's Petrochemistry Research Group and by the Executive Officer, RSES. Light refreshments were served after the presentation".

BIOGRAPHICAL MEMOIR

KENNETH RODERICK GLASSON
1921-1944

Ken Glasson died suddenly in Fiji on 27 November, 1994, in his seventy fourth year and was buried a few days later on Nananu -i-ra Island. It was the way he would have liked to go, quickly, after a refreshing swim with his wife Margaret, during a short break from his life's work, the search for, and the development of new ore bodies.

Ken Glasson was born on 7 October 1921 at Bathurst, the middle child (of five) of Kenneth Leichhardt and Melvina Mary (née Gordon) Glasson, of Cornish farming stock. Ken spent his early years in Bathurst, completing his secondary schooling at Bathurst High School, where he was School Captain in his final year, 1938. In 1939 he became a pupil surveyor with a local practitioner, continuing with his surveying experience until May, 1940.

In that month the Australian Government formed a number of new army units, including the 2/1 Survey Regiment, in which Ken enlisted on 30 May. After training at Greta and Cowra the regiment went to the Middle East in March, 1941. Ken was involved in surveys and reconnaissance in Palestine, Transjordan, the Palestine-Syrian border, and after the occupation of Syria, on its northern border with Turkey. During this time he found great interest in the historical cities and sites, visiting many during his brief periods of leave.

Japanese activities in the Pacific saw the regiment return to Australia in April, 1942, Ken's first assignment being survey work on the "Brisbane Line" of defence. In August the regimental organisation was discontinued and his troop became 2/6 Survey Battery.

The 2/6 Battery, including Ken amongst its 65 members, went to New Guinea early in 1943, spending a year on that tour of duty, producing survey information for artillery and mapping. During this period Ken was articled to an officer who was a registered surveyor. After leave and training in Queensland he returned to New Guinea, as a Bombardier and observer in charge of one of the survey parties. Early in February, 1945, as the Australian forces advanced towards Wewak, Ken received notice of early discharge and admission to a B.Sc. course at Sydney University through the C.R.T.S. scheme. He insisted on completing the survey to the limits of the infantry advance that day, before leaving next day for Australia and Sydney University. His exemplary service was recognised by the award of a British Empire Medal at the end of the campaign.

Ken kept in touch with many of his army friends, took an active interest in the Unit association, and at the time of his death, was President. In 1993 he completed (in association with some others) a history of the Regiment.

Ken plunged into his university work with enthusiasm, having already decided to concentrate on geology. He was amongst the first group of ex-service students, which joined very much younger and inexperienced students, and those who had interrupted their courses to go to war. Despite the calls of his studies Ken played a part in the Student's Geological Society and other organisations, and while in his second year of study (1946) married Margaret Robbins. By his final year Ken had made up his mind to specialise in mining geology.

Immediately on graduating at the end of 1947 Ken began his professional work at Captain's Flat, then one of Australia's largest lead/zinc mines. Beginning as Geologist, he progressed to Senior Geologist and finally Chief Geologist responsible for all mine and exploration geology, rapid promotion in less than four years.

In 1952 Ken had a brief stint of six months with CSR in Melbourne before moving to Radium Hill, South Australia, then Australia's sole uranium mine, as Project Geologist, responsible for exploration and development of the mine, planning and ore reserve calculations. The last-named matter was one that was to fascinate Ken for the rest of his life. The nearly three years at Radium Hill also gave him a taste for the Precambrian, and for the challenging geology of the Broken Hill region.

Between 1954 and 1956 Ken was Senior Consulting Geologist with Mining and Prospecting Services, a small, privately-owned company offering a wide range of mineral exploration and mining services to a number of public companies. In this period he was involved in exploration in all states and Papua New Guinea, concentrating on the

search for uranium, but also for base metals and gold. The uranium search included airborne work in the Kimberleys and extensive exploration of the Cloncurry-Mt. Isa region, shortly after the Mary Kathleen discovery. Notably he worked on the 'other side' of the structure that contained Mary Kathleen, and is credited with much of the work that led to the delineation of several uranium deposits in that region. This, and subsequent work exposed Ken to many of the early developments in Australasia's mining and exploration industry at a time when there were too few qualified professionals.

In late 1956 Ken returned to the Department of Geology and Geophysics at the University of Sydney at the invitation of Professor Charles Marshall, following the resignation of Richard Stanton. He began as a Teaching Fellow, teaching economic geology. This gave him the opportunity to write up his previous work on Captains Flat, which he submitted for the degree of Master of Science. At the end of the year he was appointed to a Senior Lectureship, with responsibility for both economic (mainly metalliferous) and engineering geology. His work entailed teaching to senior classes in Geology, and to students in Mining Engineering and Civil Engineering, getting his message over with a mixture of hands-on practical work and the benefit of his own wide local knowledge.

From the field and mine face he took his geological mapping experience and practices with him to the University where he imparted them to his students. With his belief in the need for field experience, particularly mapping, he ensured that all these groups went into the field as much as possible. He also introduced mineragraphic work and soil mechanics in his laboratory courses.

During this period Ken was consultant for a number of companies on a part-time or retainer basis. Between 1958-1962 he was involved with Consolidated Goldfields in base metal exploration in the Broken Hill, Central Western New South Wales and North Queensland regions.

In 1962 Ken was President of the Science Association, a Faculty of Science (largely student-run) organisation, but which relied on staff encouragement and active support to bring together the disparate strands within the Faculty, which also suffered from its wide physical spread on the campus. Characteristically his Presidential address was "The role of Geology and Geologists in Australia's Mineral Production".

In January 1962, Ken and his senior students undertook the exploration of the Mount Cleveland tin deposit near Waratah in western Tasmania, where they mapped and succeeded in determining the ore-forming structure, from which tin and copper concentrates were then produced for more than 20 years. Until 1969 Ken made available to the Aberfoyle Company his consulting geological services in many fields throughout Australia, particularly in the search for tin. Between 1960 and 1966 he was also consultant for various companies involved in the construction of dams and tunnels in the Snowy Mountains Scheme.

Ken's teaching and his related consulting, which provided important material for his students, gave him little opportunity for publishing papers in learned journals. While Ken enjoyed the University work there was some frustration that his teaching methods were not appreciated, and his lack of papers in technical journals, perceived as inadequate research, hindered his promotion to Associate Professor. Professor Charles Marshall finally succeeded in convincing the bureaucracy of Ken's worth, but it was too late, and the wider world was beckoning and another 25 years' exciting work began.

In 1969 Ken left the University. He had registered Foundation and Geological Services Pty. Ltd. as a company that year, and the consultant company was specifically retained, first by Union Miniére Mining and Development (Belgian owned). Ken invited some of his former students to join him in major mineral exploration and evaluation programs in Australia. This work extended from 1969 to 1975. Between 1976 and 1983 Ken and his company was Technical Adviser and Geological Consultant to Aquitaine Australia Minerals Pty. Ltd., a French-owned company, and he investigated numerous exploration ventures in Australia and Fiji. Ken's love affair with Fiji began at this time, in 1983.

From 1984 until his untimely death Ken Glasson continued his busy and productive schedule acting as consultant to a number of companies involved in the exploration for gold, base metals

BIOGRAPHICAL MEMOIRS

and non-ferrous metals in Australia and Fiji. He also practiced as a qualified engineering geologist in the Sydney-Wollongong region. During these later years he turned his attention to environmental and social matters, working for sensible solutions to local environmental and developmental problems in his home region of Kiama, gaining the confidence of public servants, community groups and the general public alike.

His participation in land deals between native peoples and mining groups in Central Australia and Fiji drew considerable praise as he gained the respect of Aboriginal people by his courtesy, friendliness and good humour. The Central Land Council recruited him to give advice to Traditional Owners and other tribal elders on exploration and mining ventures proposed in Central Australia, advice which he gave unstintingly and without charge.

Although always a strong individual, Ken's wife Margaret played an immensely important supportive role in his work throughout his life. Their family of two sons Robert and Jim was close-knit and the family treasured their times together, particularly after they moved from Sydney to Minnamurra, near Kiama.

Ken joined the Society in 1948, and when opportunity offered contributed to its activities. His single Society publication, on mineral deposits, was an important joint contribution to the Society's Centenary volume. He was a member of the Geological Society, of the Australasian Institute of Mining and Metallurgy (particularly the Joint Ore Reserves Committee, 1983-1992, Chairman 1986-1992) and a co-founder of the Australian Institute of Geoscientists (President 1983-1987). At the time of his death he was also President of the Edgeworth David Society (alumni of the Department of Geology & Geophysics, University of Sydney).

Publications of K.R. Glasson

Glasson, K.R., 1962. The role of Geology and Geologists in Australia's Mineral Production, *in* SCIENCE YEAR BOOK, 1962, pp. 22-27. University of Sydney Science Association, Sydney.

1962. Mineral Deposits in New South Wales. (with E.O. Rayner and D.K. Tompkins). *In* A GOODLY HERITAGE, pp.36-57. 36th Meeting ANZAAS, Sydney.

1965. The hydrothermal concept as a guide to ore search. *Proceedings of the 8th Commonwealth Mining and Metallurgical Congress*, 2, 19-24.

1965. Lead-zinc-copper deposits of Lake George Mines, Captain's Flat. (with V.R. Paine). *Proceedings of the 8th Commonwealth Mining and Metallurgical Congress*, 1, 423-431.

1968. Applied Geology in New South Wales. (with L.J. Lawrence). A CENTURY OF SCIENTIFIC PROGRESS, PP. 280-309. Centenary Volume, Royal Society of New South Wales, Sydney.

1989. (with other members of Joint Ore Reserves Committee, AusIMM). Code for reporting of identified Mineral Resources and Ore Reserves. AusIMM.

1990. Can Geoscientists survive the Winds of Change? *In* COAL IN AUSTRALIA. D.F. Branagan & K.L. Williams (Eds.),. Third Edgeworth David Day Symposium: 125-133.

1990. (Editor with J.H. Rattigan). GEOLOGICAL ASPECTS OF THE DISCOVERY OF SOME IMPORTANT MINERAL DEPOSITS IN AUSTRALIA. Monograph 17, AustIMM.

1991. The contribution of Mining Companies in relation to Mine Mapping and Geological Surveys. *In* GEOLOGICAL MAPPING OF TWO SOUTHERN CONTINENTS. D.F. Branagan, G.S. GIBBONS & K.L. Williams (Eds.),. First and Second Edgeworth David Day Symposia: 67-76.

1992. Gossans true and false. *In* SURFACE WITH GEOLOGY - AUSTRALIAN LANDSCAPES AND ECONOMIC IMPLICATIONS. D.F. Branagan & K.L. Williams (Eds.),. Fifth Edgeworth David Day Symposium: 20-26.

1993. (With T. Lenehan and B Sturday) LOCATING THE ENEMY! AUSTRALIAN ARTILLERY SURVEYORS AT WAR 1940-1945. A History of the 2/1 Australian Survey Regiment RAA. 2/1st Australian Survey Association, 158pp.

BIOGRAPHICAL MEMOIRS

1993. Research today-Tomorrow's development. *In* WHITHER GEOLOGICAL RESEARCH?. AUSTRALIAN GEOSCIENCE RESEARCH - IN THE NATIONAL INTEREST R.A. Facer, D.F. Branagan & K.L. Williams (Eds.),. Sixth Edgeworth David Day Symposium: 5-8.

In addition to these formal publications Ken wrote numerous Letters to the Editor of various journals and newspapers (even to Sports Editors!), which set out his ideas and positive suggestions on a variety of (often) controversial subjects.

There are also innumerable reports to Companies. These now form an important archive and hopefully will soon be housed in the Noel Butlin Archives (for Business and Labour) at the Australian National University.

D.F.B.

NORMAN FREDERICK HALL

Mr Norman Frederick Hall passed away on 13 June, 1994. He had been a member of the Society for sixty years. Having gained a MSc degree in Organic Chemistry from the University of Sydney, he joined the then Council for Scientific and Industrial Research's Tobacco Research Section and remained with the CSIR/CSIRO.

After retirement he went to live at Elanora Heights, Sydney, and while in poor health had to be evacuated hurriedly in the face of the severe bushfires which raged in January 1994. This disruption hastened the decline in Mr Hall's health. The Council is sure members join it in expressing the Society's deep sympathy to Mrs Hall and her two sons in their loss.

DOROTHY JEAN ELLISON

We also record with regret the passing of Miss Dorothy Jean Ellison. An Honours MSc graduate from the University of New Zealand, she was a science teacher at Abbotsleigh School, Wahroonga, for a period and joined the Society in 1949. She died on 5th October, 1994.

NOTICE TO AUTHORS

A "Style Guide" to authors is available from the Honorary Secretary, Royal Society of New South Wales, PO Box 1525, Macquarie Centre, NSW 2113, and intending authors *must* read the guide before preparing their manuscript for review. The more important requirements are summarised below.

GENERAL

Manuscripts should be addressed to the Honorary Secretary (address given above).

Manuscripts submitted by a non-member must be communicated by a member of the Society.

Each manuscript will be scrutinised by the Publications Committee before being sent to an independent referee who will advise the Council of the Society on the acceptability of the paper. In the event of rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere, nor is likely to be published substantially in the same form elsewhere. Well-known work and experimental procedure should be referred to only briefly, and extensive reviews and historical surveys should, as a rule, be avoided. Letters to the Editor and short notes may also be submitted for publication.

Original papers or illustrations published in the Journal and Proceedings of the Society may be reproduced only with the permission of the author and of the Council of the Society; the usual acknowledgements must be made.

PRESENTATION OF INITIAL MANUSCRIPT FOR REVIEW

Typescripts should be submitted on bond A4 paper. A second copy of both text and illustrations is required for office use. Manuscripts, including the abstract, captions for illustrations and tables, acknowledgements and references should be typed in double spacing on one side of the paper only.

Manuscripts should be arranged in the following order: title; names(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgements; appendices; references; names of Institution/Organisation where work carried out/or private address as applicable. A table of contents should also accompany the paper for the guidance of the Editor.

Spelling follows "The Concise Oxford Dictionary".

The Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigraphic names must conform with the International Stratigraphic Guide and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra, ACT 2601, Australia.

Abstract. A brief but fully informative abstract must be provided.

Tables should be adjusted for size to fit the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

Illustrations. When submitting a paper for review all illustrations should be in the form and size intended for insertion in the master manuscript. If this is not readily possible then an indication of the required reduction (such as reduce to 1/2 size) must be clearly stated.

Note: There is a reduction of 33% from the master manuscript to the printed page in the journal.

Maps, diagrams and graphs should generally not be larger than a single page. However, larger figures can be printed across two opposite pages.

Drawings should be made in black Indian ink on white drawing paper, tracing cloth or light-blue lined graph paper. All lines and hatching or stripping should be even and sufficiently thick to allow appropriate reduction without loss of detail. The scale of maps or diagrams must be given in BAR FORM.

Half-tone illustrations (photographs) should be included only when essential and should be presented on glossy paper.

Diagrams, graphs, maps and photographs must be numbered consecutively with Arabic numerals in a single sequence and each must have a caption.

References are to be cited in the text by giving the author's name and year of publication. References in the reference list should follow preferred method of quoting references to books, periodicals, reports and theses, etc., and be listed alphabetically by author and then chronologically by date.

Titles of journals should be cited in full – *not* abbreviated.

MASTER MANUSCRIPT FOR PRINTING

The journal is printed by offset using pre-typed pages. When a paper has been accepted for publication the text may either be typed by electric typewriter or produced by word-processor print-out: Print-out or typing should be in a column exactly 105 mm (= 4 1/8 inches) wide. Type size should be 14 point (Roman preferred) or 12 pitch single-spaced (IBM Adjutant preferred).

Reprints An author who is a member of the Society will receive a number of reprints of his paper free. An author who is not a member of the Society may purchase reprints.

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THE ROYAL SOCIETY OF NEW SOUTH WALES

The Society originated in the year 1821 as the Philosophical Society of Australasia. Its main function is the promotion of Science through the following activities: Publication of results of scientific investigation through its Journal and Proceedings; the Library, awards of Prizes and Medals; liaison with other Scientific Societies; Monthly Meetings; and Summer Schools for Senior Secondary School Students. Special Meetings are held for the Pollock Memorial Lecture in Physics and Mathematics, the Liversidge Research Lecture in Chemistry, and the Clarke Memorial Lecture in Geology.

Membership is open to any interested person whose application is acceptable to the Society. The application must be supported by two members of the Society, to one of whom the applicant must be personally known. Membership categories are: Ordinary Members, Absentee Members and Associate Members. Annual Membership fee may be ascertained from the Society's Office.

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The Society welcomes manuscripts of research (and occasional review articles) in all branches of science, art, literature and philosophy for publication in the Journal and the Proceedings.

Manuscripts will be accepted from both members and non-members, though those from non-members should be communicated through a member. A copy of the Guide to Authors is obtainable on request and manuscripts may be addressed to the Honorary Secretary (Editorial) at the above address.

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ISSUES IN ASSESSING THE LONG-TERM STABILITY OF ENGINEERED LANDFORMS AT RANGER URANIUM MINE, NORTHERN TERRITORY, AUSTRALIA

S.J.Riley

ABSTRACT

Assessment of the long-term stability of engineered landforms of rehabilitated uranium mines and uranium mill tailings containment structures is primarily a geomorphic issue. It involves consideration of site stability, containment stability and the dispersion of the products of weathering and erosion and hence relies on models of the hydrogeomorphic environment.

For Ranger Uranium Mine geomorphic assessment has defined areas with the least risk of instability and the erosional stability of uranium mill tailings containment structures has been modelled using the geomorphic model SIBERIA. Assessment of the dispersion of products throughout the receiving fluvial system is critical in setting the guidelines for acceptable levels of erosion and risk to the environment of failure of the containment structure.

Design and assessment is ultimately an issue of acceptable probabilities of failure (risk), which are set by society. The geomorphic research is directed towards assessing whether or not the designs meet acceptable standards.

INTRODUCTION

Uranium mill tailings require containment and isolation from humans and the environment for thousands of years (Commonwealth of Australia, 1987). During these long periods the geomorphic stability of cover materials and sites will be critical in determining whether or not engineered structures maintain their integrity (Schumm et al., 1981, 1982; Pidgeon, 1982; East, 1986; Riley et al., 1993; Riley, 1994). The assessment of rehabilitation and containment stability must rely on geomorphic modelling because there is no other tool outside of modelling with which long-term stability can be assessed.

The geomorphic models cannot be considered as anything other than predictive tools for estimating probabilities of success of rehabilitation and containment (Riley and Waggitt, 1992a,b; Waggitt and Riley, 1992; Willgoose, 1993) as forecasting is precluded by the chaotic nature of micro-relief, stratigraphy and micro-processes of erosion and weathering. For example, prediction of gully development on engineered landforms is possible (Nelson et al., 1983, 1986), but forecasting the exact location and geometry of individual gullies is unlikely. Thus, the assessment of geomorphic stability is concerned with predictions that are probabilistic, not deterministic. Further, assessment must be based on risk to the environment of failure, which incorporates the probabilities of failure and impact of the failure.

This paper briefly discusses issues that have been considered in assessing the geomorphic stability of uranium mill tailings containment structures at Ranger Uranium Mine (RUM), Northern Territory, Australia. The purpose of the paper is to present the conceptual approach to addressing the issues. Results of studies completed to date are briefly discussed, reference being made to the relevant reports detailing the results.

RANGER URANIUM MINE

Ranger Uranium Mine (RUM) is surrounded by the World Heritage Listed area of Kakadu National Park (Fig 1) and is within the Magela Creek valley.

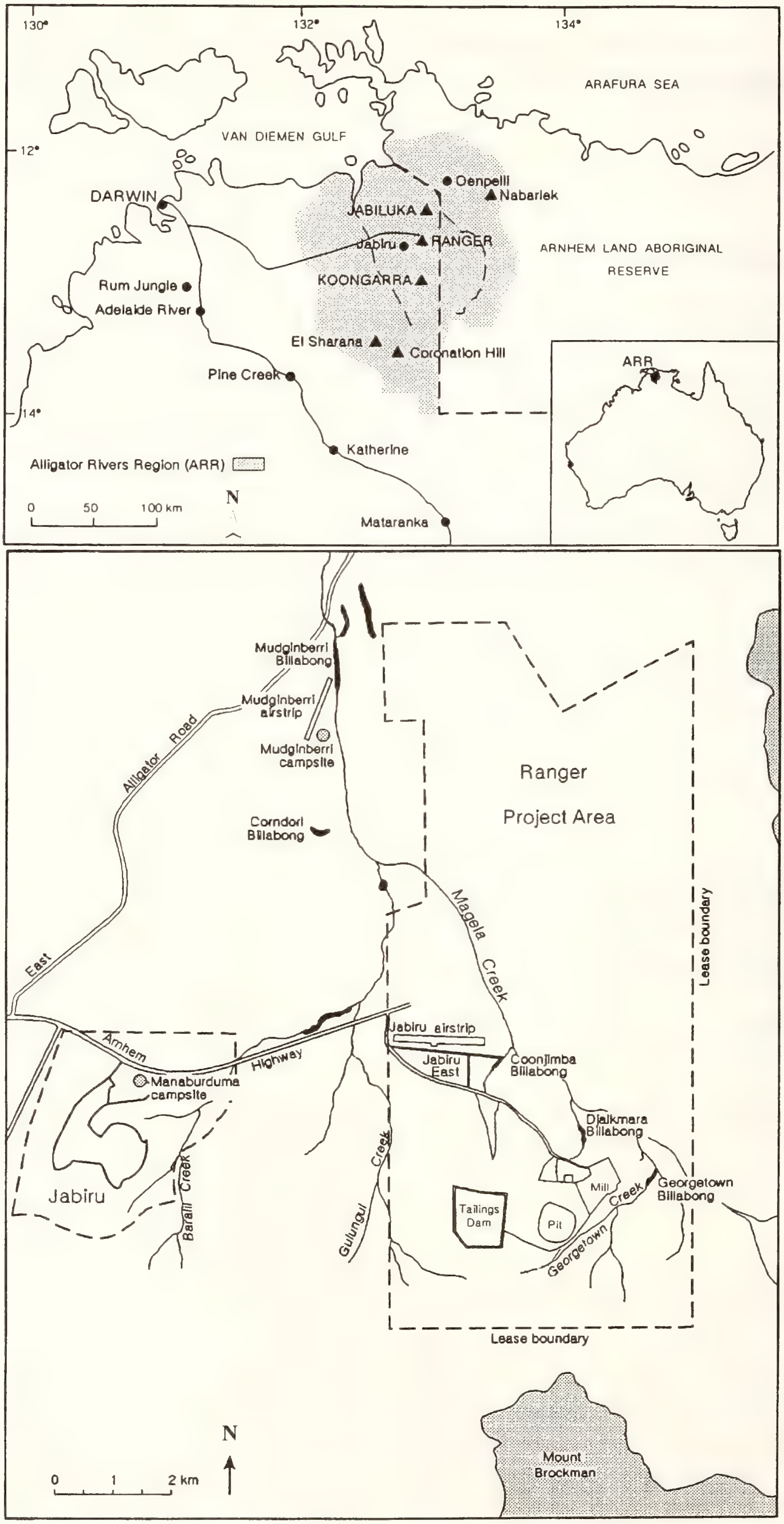

Figure 1. Location of Ranger Uranium Mine, Northern Territory, Australia.

The valley is occupied by its traditional aboriginal owners and downstream of the mine is a substantial area of wetlands. Hence, there are both human and environmental reasons for confirming that the rehabilitation of RUM, and specifically the containment of the mill tailings, will be within guidelines and that the highest standards will be achieved (Fox, 1977).

There are several guidelines and constraints that are relevant to the rehabilitation of uranium mill tailings at RUM, in particular the Code of Practice on the Management of Radioactive Wastes (Commonwealth of Australia, 1987), the Commonwealth and Northern Territory Governments' agreed goals and objectives, and the Environmental Requirements (Commonwealth of Australia, 1979) that applied to the granting of the licence to mine. Inherent within these goals, objectives and guidelines are explicit and implicit statements on the stability, weathering and erosion of the rehabilitated mine which will be briefly reviewed in the following.

The Guidelines of the Code of Practice on the Management of Radioactive Wastes from the Mining and Milling of Radioactive Ores 1987 (Commonwealth of Australia, 1987) recognise two periods for the containment structures, namely the design life and the structural life. The recommended design life is 200 years, the structural life is 1000 years. In the US the design life may be much greater than 200 years (Waggitt, 1994) but should not to be confused with the design life for containment structures of high level radioactive substances.

Structural life is the period over which a structure is expected by the designer to continue to perform its basic functions, even if at a reduced level. It should be recognised that a specified design or structural life is not a statement that the structure will not fail in either of these periods. Any engineering structure has a finite probability of failure. The critical issue is that the structure will have a probability of failure that is low and acceptable, as expressed by the period of the design and structural lives.

The goals and objectives for rehabilitation at Ranger aim to establish a post-mining environment that is similar to the adjacent areas of Kakadu National Park, with similar vegetation, stable radiological conditions and dose limits as low as reasonably achievable, and erosion rates as low as those of the surrounding area. These goals and objectives need to be examined in terms of the predictions made by the biophysical modelling of options for rehabilitation. For example, the erosion standards are updated with the continual assessment of the environmental impacts and hazards of dispersed erosion products (Waggitt and Riley, 1992).

GEOMORPHIC ISSUES

The three main geomorphic issues related to the geomorphic stability of engineered landforms at Ranger are the probable stability of the site, the probable life of the containment structure, and the likely sediment loads and deposition sites (Pickup *et al*, 1987; East, 1986) (Fig 2). The issues have to be considered in terms of the constraints on design of rehabilitation structures, such as cost and risk to the environment, and the geomorphic processes that dictate the stability conditions, principally weathering and fluvial erosion. The results of deliberations on issues are expressed in the preferred options for the design of the rehabilitation structures, which are then evaluated by modelling.

These three issues can also be examined in terms of the on-site and off-site issues of geomorphic stability. On-site it is the nature of the products of mining disposed of on-site, the characteristics of processes that release these materials and the loads, concentrations and toxicity of materials exported to off-site areas that are of concern. The issue of the integrity of the engineered (artificial or designed) landforms arises in on-site considerations. The stability of an engineered landform will influence the amount, rate and form of export of material. The two main potential sources of contaminants exported to off-site areas are the mill tailings and the waste rock dumps (Pidgeon, 1982; Ellis, 1989).

Off-site concerns are impact related. Large quantities of material may be exported off-site but may have no impact either because they are benign or because they are deposited in sinks where impacts are negligible. Off-site impact analysis requires an understanding of the sensitivity of the receptive environment to the influx of materials. Off-site

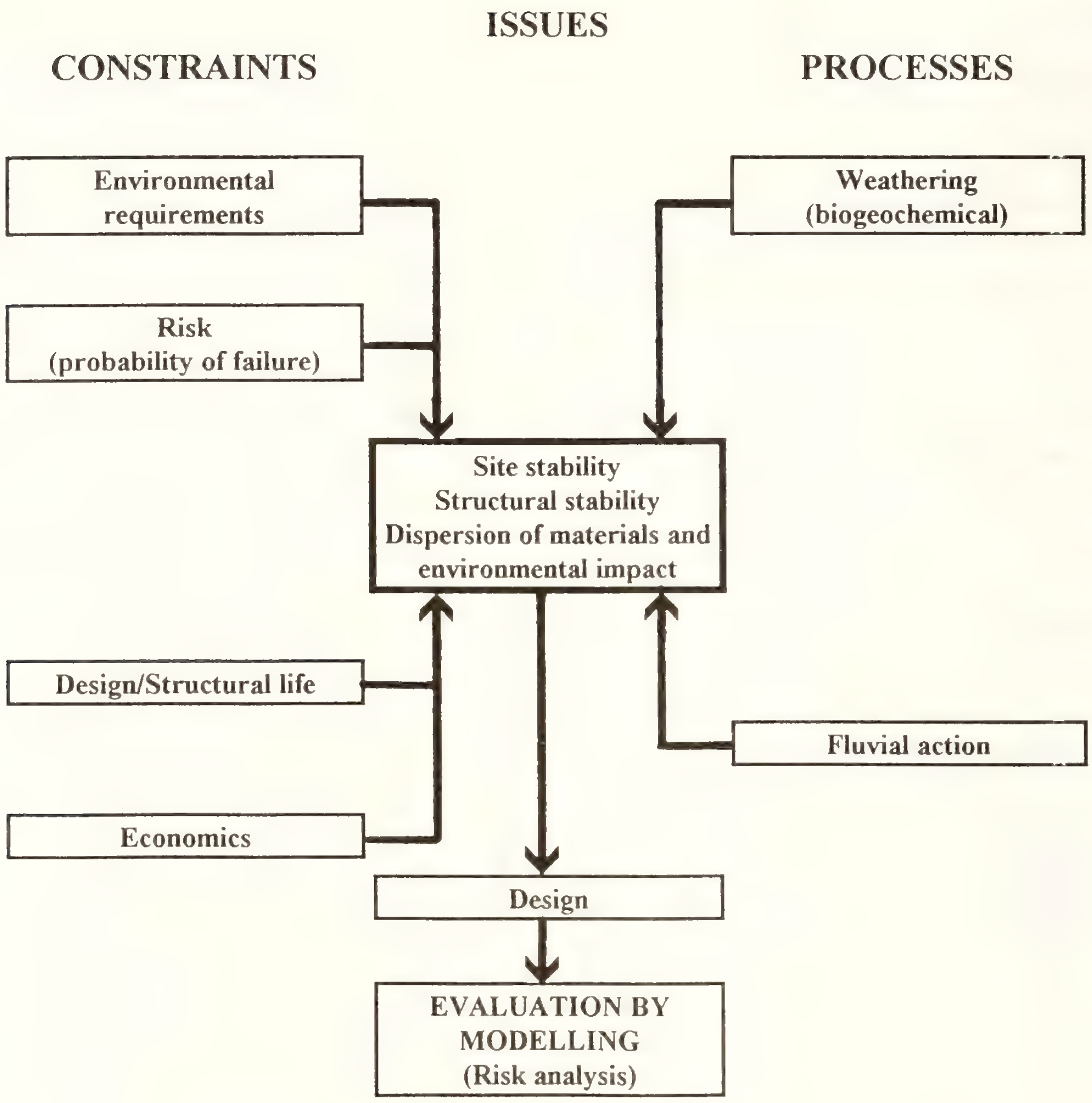

Figure 2. Conceptual model of geomorphic issues, processes and constraints in the assessment of mill tailings containment structure. Refer to text for details.

concerns dictate boundary conditions for the design of the rehabilitation structure. Erosion rates must be below levels that impact on the environment of the transport corridors and sediment and solute sinks. Of the four major processes by which material may be eroded and moved from the mine site to surrounding areas (Gray and Boyer, 1981) fluvial activity is dominant at Ranger (Pickup et al., 1987; Duggan, 1988; Riley and East, 1990).

Each of the three geomorphic issues is examined in the following.

PROBABLE STABILITY OF THE SITE

Detailed surveys of the geomorphology of the Ranger lease area, which included dating of the main landform elements and stability analysis of small streams, suggest that the primary rehabilitation sites are stable in the long term. The areas of greatest instability are the main streams and the immediately adjacent areas. Details of the analyses are provided in East et al. (1993) and Duggan (1988). Duggan suggests that erosion rates in natural areas around Ranger are of the order of 0.01-0.1 $mmyr^{-1}$ and are significantly increased by land disturbance. This estimate of denudation provides an 'ultimate' target for erosion rates on the engineered landforms although recent work by Nott (1994) would suggest that the long-term denudation rate is much lower.

Magela Creek has aggraded significantly in the last 10,000 years but for the present appears to be stable near Ranger. Thus, it is unlikely that the stable interfluve landforms around the mine site will become unstable as a result of river instability (Nanson et al., 1990; Roberts, 1991; East et al., 1993). It is highly

unlikely that very low frequency floods will create instability (Murray et al., 1992).

Probable life of the containment structure

Details of the research undertaken to assess the stability of the containment structure is presented in Riley (1994). Essentially, the problem is one of establishing the long-term weathering and erosion regime, taking account of termporal variations that arise from ecosystem development on the engineered landforms, and then calibrating suitable geomorphic models.

Weathering and associated ecosystem development on engineered landforms introduces to modelling the complication that the surficial properties change over time. The biophysical reactions at and near the surface change the hydraulic properties and erodibility of the materials (Riley, 1994). Changes in landform shape as a result of erosion, eg the development of gullies, impose changes in the drainage network and slope gradients and often the nature of erosion. An unstable structure would not allow soil development to progress to the point where a stable system could develop, that is the ecosystem would be degraded or unable to develop. Large quantities and rates of sediment discharged into the adjacent environment would exacerbate off-site impacts, such as infilling of billabongs, changes in the substrate of streams and floodplains, increases in turbidity, and ecological changes arising from these sedimentological changes (Riley and Waggitt, 1992a,b). The discharged sediments would initially be the weathering products of the containment structure. Once the containment structure was breached the sediments would include tailings.

One proposed rehabilitation structure at Ranger (Unger et al., 1989) would incorporate the existing above ground tailings dam (1km^2 in area) and use the waste rock as a cover material. The final landform would be more than 4km^2 in area and rise more than 17m above the surrounding lowlands. The waste rock is dominated by a highly chloritised schist, which weathers rapidly in the seasonally wet tropical climate, producing large quantities of easily eroded materials (Uren, 1991).

Two main agents of fluvial erosion that will affect the stability of the rehabilitation structure are interrill erosion, dominated by rainsplash and wash, and the complex of processes associated with rilling and gullying. Gullying is not evident on many gentler slopes of the region, but is common in schist areas with relief in excess of 10 metres (Riley and Williams, 1991). Wash and rainwash erosion processes are well documented for the area (Williams, 1978; Duggan, 1988). A combination of monitoring and simulation experiments have been used to collect the data required to define these key hydrogeomorphic processes and calibrate the models of these processes. Simulation experiments incorporate the use of a rainfall simulator (Riley and East, 1990; Riley and Gardiner, 1991) and concentrated flow simulator (Riley, 1992), both specifically designed for the project (Fig 3). The latter uses a 12m long race through which water is discharged and depths of erosion, sediment concentration and bedload measured (Fig 3).

There are two approaches to erosion modelling, soil erosion modelling and geomorphic modelling. Soil erosion modelling assists in predicting sediment and hydrologic characteristics of the immediate time. However, soil erosion models do not allow for interaction between the development of landforms and the erosion processes. Geomorphic modelling is the approach that is used when the modelling has to simulate processes over long periods. There are significant differences between the two approaches (Willgoose, 1993) but they can be complementary. For example, the geomorphic modelling predicts landform development over the long term and, at specific times, the predicted landform and material characteristics can be used as input to soil erosion models. These soil erosion models may include water quality and productivity modules.

Geomorphic modelling of containment structures at Ranger uses the model SIBERIA (Willgoose and Riley, 1993a,b) which explicitly incorporates the interaction between the hillslopes and the growing channel or gully network. The model has two main components. The first component is a model of elevation variation; the second component models the position of channels in the catchment. The channels develop in response to changes in elevation and, in turn, the elevations change in response to the channels. Further details of the model, including the assumptions in its application, and sensitivity analysis are given in Willgoose and Riley (1993a,b)

Figure 3a. A rainfall simulation experiment, in which the processes of interrill erosion are studied by monitoring the water and sediment discharge and hydraulic conditions of runoff under specified rainfall intensities.

Figure 3b. A concentrated flow simulation experiment, in which the discharge of water through the race, sealed to the surface, provides data on the processes of erosion of the surface under controlled hydraulic conditions.

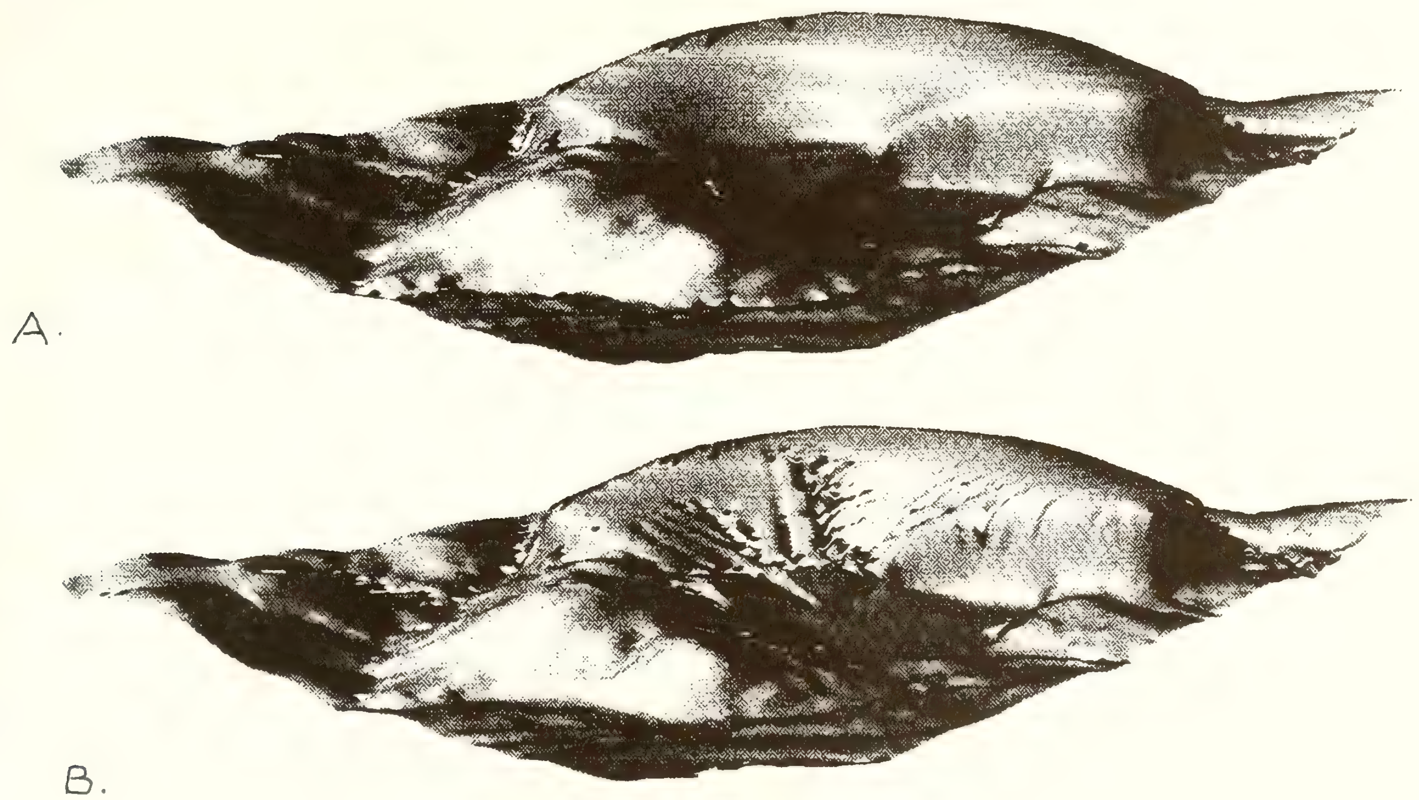

Figure 4. SIBERIA predictions of landform changes as a result of erosion of the above ground option for rehabilitation of the Ranger uranium mill tailings. The upper diagram (A) shows the engineered landform proposed by Ranger Uranium Mines in its pristine condition. The lower diagram (B) shows the landform after 1000 years of erosion. Note the major gully system in the central area. The view is from the north east looking south west and each side of the block is approximately 3km long.

Geomorphic modelling of Ranger rehabilitation structures shows that there is substantial erosion in the central section of the proposed rehabilitation structure and on the margins of the steeper batter slopes (Fig 4). Erosion in some areas exceeds 8m in depth after 1000 years. Detailed work on the sensitivity of the model to settlement in the structure suggests that denudation rates are increased and valley incision enhanced by the chaotic redefinition of topography (Willgoose, 1993).

SEDIMENT LOADS, DEPOSITION SITES AND ENVIRONMENTAL RISK

The third issue concerns the dispersal of products eroded from the rehabilitation structure. Aspects of the assessment of the environmental impact of dispersed products, an essential element of risk analysis, is dependant on the ability to predict the quantities, rates and nature of products eroded from the mine site and discharged into the tributary streams. The likely locus of deposition of fine-grained material transported by Magela Creek is a 30km^2 area immediately downstream of Mudginberri (Wasson, 1993). Examination of tailings dispersal in the catchment of the old Hercules Mine at Moline, south of Ranger (East et al., 1988), suggests by analogy that tailings released in catastrophic circumstances from Ranger will probably disperse over the floodplain and through the channel systems, with swales, billabongs and other low points in the landscape being preferential deposition sites. Irrespective of catastrophic events, it is certain that erosion of the engineered landforms of Ranger will lead to more rapid infilling of billabongs and changes in the sedimentology of the streams that drain the mine site (Riley and Waggitt, 1992a,b).

Magela Creek carries an annual load of approximately 5000 tonnes of silt-clay and an equivalent amount of coarser grained suspended and bed loads (Roberts, 1991). The impact on sediment transport systems of sediment eroded from the rehabilitated mine and deposited in Magela Creek can be gauged by comparing the natural load with the additional load. The estimated natural sediment load also can be used to establish a 'dilution' factor for eroded sediment, which will assist in setting standards for release of eroded materials.

The analysis of environmental risk, which will set the constraints for the design of the containment structure is still a matter of research (Riley and Rippon, in prep), although aspects of risk analysis for rehabilitated landforms is discussed by Waggitt and Riley (1994).

DISCUSSION

Each of the three geomorphic issues of site stability, probable life of the structure and sediment loads and deposition regimes is highly connected. Failure of site stability will lead to failure of the structure which will lead to higher rates of sediment discharge into the surrounding environment. Design must take account of all three issues and sometimes compromises have to be reached. For example, a structure may be made more stable by adopting low angle slopes and a lower height, but the consequence is a structure that covers a larger area. A large area structure may overlap high risk areas in terms of site stability and may directly connect to drainage lines and not allow for buffer zones.

Ultimately the decision on the acceptable level of risk and environmental impact is one that has to be made by society (Whyte and Burton, 1980; Douglas and Wildavsky, 1982; Dreith, 1982). However, ecological and human safety issues, while important in assessing the design, only set the boundary conditions. As long as design specifications meet the environmental concerns then there is flexibility within the guidelines for different design options (Waggitt and Riley, 1994). A number of solutions may be developed for stablizing structures but cost may mitigate their usefulness. While technological developments during the life of a mine may also influence design decisions and rehabilitation options, economic considerations dictate that rehabilitation issues have to be considered at all stages (Jackson, 1991; Bell, 1990, 1993). Costs of reshaping landforms are high and mine managers seek to minimise these by placing waste material directly in its final position.

Thus, in assessing and designing containment structures and engineered landforms it is important to realise the constraints on design and management. Acceptable levels of risk will have to be balanced against cost. The design and the assessment of a rehabilitation structure will use one or more models to evaluate the design and establish whether it meets guidelines and standards. The design-modelling step is iterative, as the design will be modified if the assessment by modelling suggests that design criteria are not achieved. In some situations where design specificiations cannot be met it may be necessary to revisit constraints and renegotiate them (Evans and Riley, 1994). Ultimately the geomorphologist can only make assessments and suggestions based on the key issues. The risk and cost issues are matters of public and company concern. In a contentious industry such as uranium mining in a sensitive area like Kakadu, some of the decisions on rehabilitation are clearly in the ambit of the politicians.

CONCLUSIONS

Geomorphic surveys have established that the proposed site for rehabilitation of the uranium mill tailings is amongst the most stable in the area and will probably be stable over the structural life of the containment structure.

The principal geomorphic processes that will influence the stability of the Ranger uranium mill tailings containment structure are related to the fluvially dominated processes of gullying and interrill erosion. Monitoring and simulation experiments at a number of sites are directed towards development of models to predict the erosion and hydrology of the surface of the containment structure. The eventual outcome of this research is a geomorphic model that can be used to predict the long-term stability of the

structure and provide a tool for design of a structure that meets guidelines and standards.

The first phase of modelling has suggested design problems with one proposed rehabilitation structure for Ranger. The depths of erosion and the development of gullying are likely to put at risk the containment of tailings for the above ground option and will lead to large quantities of sediment being discharged off-site. The visual degradation of the site will be considerable over the thousand year period. There is an interactive process of design and testing with best available models that will lead to a more secure rehabilitation structure at Ranger Uranium Mine.

Risk analysis of the rehabilitation and containment structures of Ranger will be based on the potential impact on the environment as well as economic and social considerations. Initial studies of the redistribution of material eroded from Ranger suggests that the greatest areas at risk are the tributary streams within the lease area and an area of floodplain immediately downstream of Mudginberri Lagoon.

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THE OCCURRENCE AND ORIGIN OF WELL-CRYSTALLISED UVAROVITE GARNET FROM THE PODIFORM CHROMITITE DEPOSITS OF SOUTH-EASTERN NEW SOUTH WALES.

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ABSTRACT. Chromian garnets occur within three podiform chromitite deposits in south-eastern N.S.W. Fourteen new analyses of these garnets are presented in this paper and these reveal that the garnets are either uvarovite or chromian grossular in composition. These analyses, along with analyses of uvarovite garnets from other world occurrences, suggest that there is no distinct relationship between the composition of uvarovite garnets and the geological setting in which they occur. Although the composition of the chromium-bearing garnets from the two deposits which are examined in some detail in this paper are quite different, their environment of formation was similar. All of the Cr-bearing garnets have formed during calcium metasomatism congruent with localised remobilisation of chromium.

INTRODUCTION

Uvarovite (or chromian garnet), the rarest of the six common species of the garnet group (Deer *et al.* 1982), rarely occurs in well formed crystals.

Well-formed bright green garnet crystals, on a matrix of chromitite occur at several localities in south-eastern NSW associated with podiform chromitite deposits (Graham *et al.* 1991). X-ray diffraction, refractive index determinations and SEM analysis have shown that these garnets are Cr-bearing. Chromium garnets from this region of N.S.W were first described by Golding and Bayliss (1968) and Ashley (1969). But to the authors' knowledge, this paper presents the most detailed study on the chromian garnets of this region of NSW and presents analyses of these garnets for the first time.

REGIONAL GEOLOGICAL SETTING

A series of N-S trending serpentinite belts occur in the south-eastern portion of NSW (Figure 1). The two largest belts are known as the Coolac Serpentinite Belt (CSB) and the Wambidgee Serpentinite Belt (WSB). Chromian garnet crystals have been discovered within both these belts.

The belts are emplaced into a variety of early and middle Palaeozoic strata and are exposed over a total linear distance of 230 km (Franklin *et al.* 1992). They vary in size from small lenses less than 5m in length, up to a single large body which crops out continuously for some 56km and are composed of variably foliated harzburgite and dunite. All of the belts contain varying amounts of primary, weakly serpentinised ultramafic rocks (i.e. wehrlite, lherzolite) as well as talc-carbonate bodies and rodingite dykes. Podiform chromitite bodies have been found in the CSB and WSB with associated minor platinum-group element (PGE) mineralisation (Franklin *et al.* 1992).

The belts differ in their degree and nature of alteration, metamorphism and deformation. Overall, the degree of metamorphism ranges from lower greenschist facies assemblages (lizardite-chrysotile assemblages within the CSB) to the uppermost amphibolite facies (garnet and pyroxene-bearing amphibolites in the WSB), indicating a temperature variation from as low as 150^{o} C to some 700^{o} C. Gross lithological and meso-scale mineral layering are observable within the CSB and fibre-vein foliations and S-C dominated shear fabrics occur in all of the belts. Controversy exists regarding the origin, emplacement history, and relative and absolute age of these belts as well as the possible relationship between the different belts.

GEOLOGY OF THE CHROMIAN GARNET MINERAL OCCURRENCES

Well-crystallised chromian garnets have been found within the CSB and WSB. In both cases, the garnets occur on a matrix of chromite and are restricted to the podiform chromitite bodies. These bodies include: the MLA deposit (CSB), Kangaroo East Mine (CSB) and the Fontenoy chromite mine (WSB). The largest crystals (up to 2mm in diameter) occur at the Fontenoy chromite mine whereas the best formed, most transparent crystals occur at the MLA deposit (generally less than 1 mm in diameter). In all cases the garnets are localised and exist as fracture-fill minerals associated with chromian clinochlore.

At the MLA deposit, the chromian garnet occurrence is restricted to a narrow area (some 2 m by 2 m) where the chromitite body is in contact with a metasomatite dyke. The chromitite itself is moderately fractured and contains approximately 80% Al-rich chromite with the remaining 20% consisting of chrysotile, talc and magnesite. The garnet occurs as a fracture lining within the chromitite and is often associated with chromian clinochlore. The metasomatite

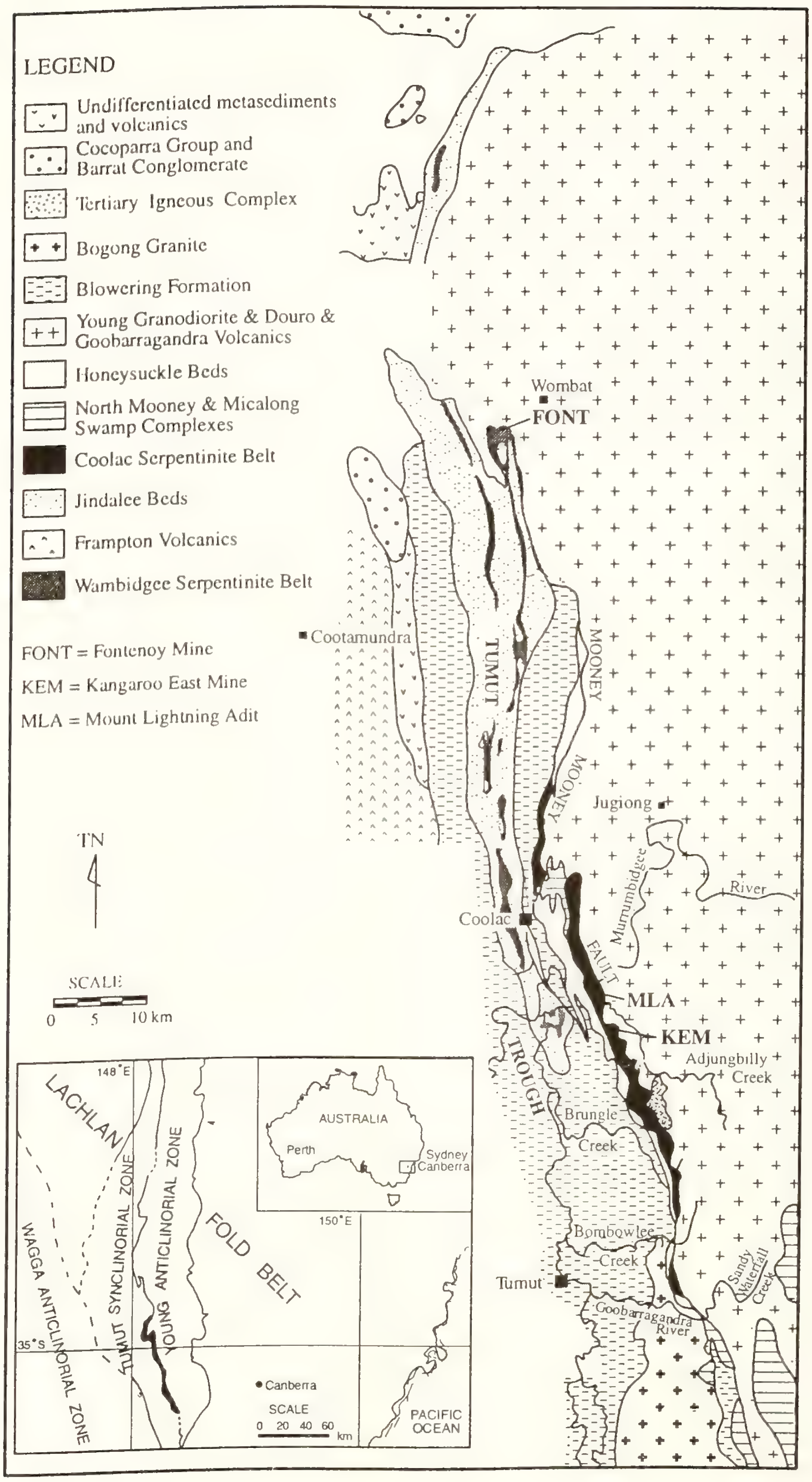

Figure 1: Locality map showing the distribution of the serpentinite belts and chromian garnet occurrences.

consists of the minerals albite, biotite, vermiculite, prehnite and pyrophyllite.

Spatially associated with both the chromitite body and the metasomatic dyke are veinlets and small dyke-like bodies of massive rodingite. This rodingite consists mainly of prehnite with minor vermiculite. It would appear that both the rodingite and metasomatite are related to each other and that they have played an important role in the formation of the uvarovite.

The Fontenoy chromitite body crops out in a creek bed on Fontenoy station near the town of Wombat. Again, the chromitite body is moderately fractured. Chromian garnet again occurs as a fracture lining within the chromitite and is associated with chromian clinochlore and diopside. In rare cases, the garnet occurs as a fracture lining within a diopside dominated granoblastic rock. The garnet appears to be evenly distributed throughout the deposit and is of fairly common occurrence at this locality. No metasomatites or rodingites

Fontenoy Garnets			MLA Garnets		
(hkl)	dÅ	a_0Å	(hkl)	dÅ	a_0Å
(400)	2.996	11.985	(400)	2.970	11.882
(420)	2.680	11.985	(420)	2.660	11.896
(422)	2.446	11.830	(422)	2.468	12.090
(611)	1.944	11.930	(611)	1.931	11.903*
(642)	1.602	11.988	(642)	1.609	12.040*
	(average)	11.985		(average)	11.962
R.I. = 1.855 (+,- 0.003)			R.I. = 1.853 (+,- 0.003)		

* indicates rather broad peaks

Table 1: Principle d-spacings, unit cell dimensions and refractive indices for Fontenoy and MLA garnets.

occur, however diopside-clinochlore dominated rocks are closely associated with the chromitite body.

At the Kangaroo East mine, minute chromian garnets were found on the mine dumps but their actual occurrence within the mine is unknown. Again the garnets occur on chromite and are associated with chromian clinochlore and an unidentified secondary amphibole. Clinochlore is a common constituent as a fracture fill mineral in the chromitite of this mine and rodingite dykes are known to exist within the general area although none are visible in the actual vicinity of the mine itself. Not enough material was collected from this source to test.

METHODS USED TO DETERMINE THE GARNET COMPOSITIONS

Refractive index (RI) and unit cell measurements

The refractive index of the garnets was determined by the Becke line method using Cargille RI liquids. Their refractive indices were checked using a Leitz-Jelley refractometer using sodium light.

Powder XRD charts were made of the garnets and they closely matched the JCPDS card 11-696 for uvarovite. The charts were run on a Philips PW1840 diffractometer, the alignment of which was checked using silicon powder as a standard. Charts were run from 2^o (2θ) to 70^o (2θ) using Co K alpha radiation under the following conditions:- speed, 0.02^o 2θ/sec; chart speed 10mm per 1^o 2θ; chart range 2000 c/s and a time constant of 1 sec.

The unit cell sizes of the garnets were calculated as an average, using the standard formula;

a_o Å = $d_{(hkl)}$ $(h^2+k^2+l^2)^{1/2}$ from five d spacings.

Scanning Electron Microscope (SEM) Investigations

The chromian garnet crystals were scraped-off selected samples and mounted in epoxy resin before being polished. The garnets were then analysed using a JEOL 6300F Force Electron Gun Scanning Electron Microscope (FEGSEM) at the Regional Research Facility for Microscopy and Microanalysis at UTS. The accelerating voltage was 15kV, the beam current 0.3nA and the counting time was 200 seconds. Also, the actual beam width is only a few nm. Although the analyses are 'standardless analyses', the accuracy of this procedure has been checked by re-analysing a selection of minerals of known composition. The differences were never greater than 2%.

Garnet composition.

Principle d-spacings, unit cell dimensions and refractive indices for Fontenoy and MLA garnets are given in Table 1. From the data (Table 1), one can see quite clearly that the unit cell values (a_o Å) are distinctly different between the two deposits but that the average RI values are very similar. The average unit cell size for the Fontenoy garnets is appreciably higher than that for the MLA garnets.

The results (Tables 2 and 3) show that the garnets vary considerably in composition between the two different localities and that there is also some variability within an individual locality.

Garnets from the Fontenoy deposit can be classified as uvarovite. Grossular, together with andradite, make-up the majority of the remaining garnet molecules. Small amounts (5.30 to 7.80) of pyrope occur in 3 of the 6 analyses, indicating some Mg in the environment of garnet formation. The most variable oxides are TiO_2, MgO and FeO (Total Fe) while the other oxides (SiO_2, Al_2O_3, Cr_2O_3 and CaO) occur in similar amounts.

	a_0Å	R.I.	wt. % Cr_2O_3	wt.% CaO
End Member (D.H. & Z 1982)[1]	11.996	1.865	30.37	33.62
analyses 5 (Frankel 1959)[2]	11.961	1.830	11.49	33.26
analyses 10 (Frankel 1959)[2]	11.975	1.837	14.83	32.81
analyses 2 (von Knorring 1951)[3]	11.892	1.798 - 1.804	14.97	33.08
analyses 3 (von Knorring 1951)[3]	11.922	1.821 - 1.829	22.60	34.25
Fontenoy	11.985	1.855	15.96	37.91
MLA	11.962	1.853	11.83	39.30

Table 2: Table comparing physical and chemical properties of uvarovite garnets from various localities.

[1]Deer, W.A., Howe, R.A. and Zussman, J., (1982). ORTHOSILICATES VOLUME 1A. 2nd edn. Longman Publishing, London and New York, p.473.
[2]Frankel, J.J., (1959). Uvarovite garnet and South Africa jade (hydrogrossular) from the Bushveld Complex, Transvaal. *The American Mineralogist, 44,* table III p. 571.
[3]von Knorring, O., (1951). A new occurrence of uvarovite from northern Karelia in Finland. *Mineralogical Magazine, 29,* table IV p. 599.

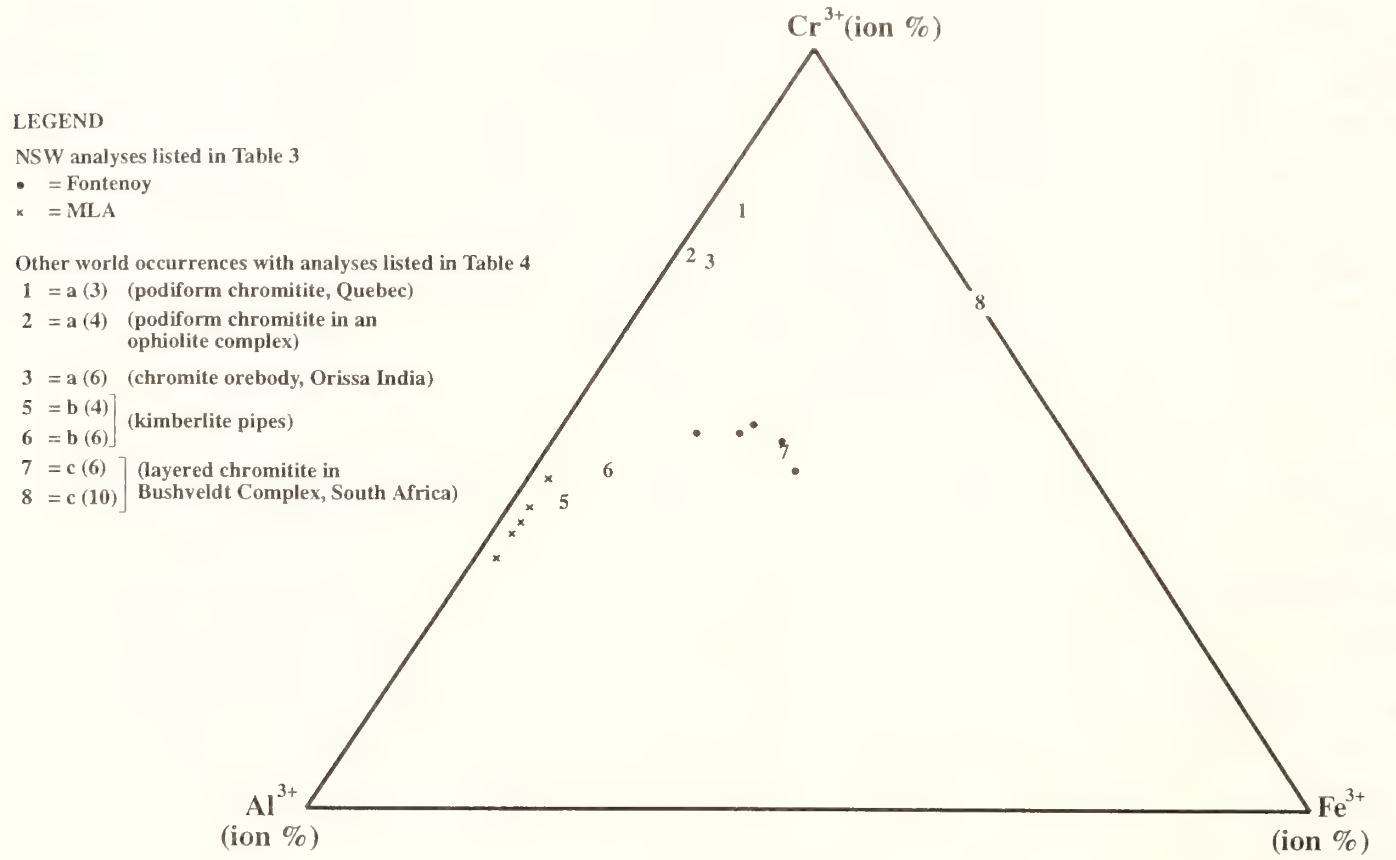

Figure 2: Al^{3+}- Cr^{3+}- Fe^{3+} Triangular diagram of uvarovite garnets

Garnets from the MLA deposit are classified as grossulars. Uvarovite is the next most abundant with only minor amounts of andradite and pyrope being present. These garnets are Al-rich (containing some 10.74 to 13.09 Al_2O_3) and very Fe-poor (0.41 to 0.76 FeO (Total Fe). Unlike the garnets from the Fontenoy deposit, the most variable oxides within the MLA garnets are Cr_2O_3 and Al_2O_3, with similar amounts of SiO_2, CaO and FeO (Total Fe) occuring within all of the garnets analysed.

On the Al^{3+}-Cr^{3+}-Fe^{3+} triangular diagram (Figure 2), the garnets from both deposits fall within very discrete fields. Due to the low and constant Fe^{3+} content of the MLA garnets, they almost fall on the Cr^{3+}, Al^{3+} join whereas those from the Fontenoy deposit fall within the middle of the triangular diagram.

TABLE 3

Garnet Analyses (weight %)

	1 Font.		2 Font.		3 Font.		4 Font.		5 Font.		8 Font.	
SiO_2	31.94		32.14		32.05		33.13		32.89		31.23	
TiO_2	1.5		1.63		1.44		1.73		1.37		1.25	
Al_2O_3	6.24		6.57		5.72		6.93		6.16		5.95	
Cr_2O_3	16.80		15.63		15.67		15.49		16.22		14.07	
CaO	37.95		38.38		37.69		38.13		37.40		38.06	
MgO	0.25		-		-		0.15		0.19		1.29	
$FeO_{(TOT)}$	5.32		5.65		7.43		4.43		5.77		8.15	
Total	99.99		99.98		100.00		100.00		100.00		100.01	
Number of ions on the basis of 24 (O)												
Ca^{2+}	3.098		3.138		3.078		3.105		3.060		3.093	
Fe^{2+}	-	3.01	-	3.12	-	3.08	-	3.12	-	3.08	-	3.26
Mg^{2+}	-		-		-		0.019		0.025		0.164	
Al^{3+}	0.594		0.676		0.594		0.707		0.634		0.613	
Cr^{3+}	0.985	1.90	0.978	2.00	0.985	2.15	0.966	1.88	1.015	2.11	0.874	2.08
Ti^{4+}	0.090		0.102		0.090		0.107		0.086		0.077	
Fe^{3+}	0.479		0.362		0.475		0.283		0.370		0.518	
Si^{4+}	2.754	3.00	2.745	2.86	2.754	2.75	2.814	3.00	2.810	2.92	2.660	2.66
Al^{3+}	0.246		0.118		-		0.186		0.106		-	
Uvarovite	47.5		46.6		48.0		46.4		49.4		41.9	
Andradite	27.0		21.9		27.7		18.8		22.2		28.6	
Grossular	25.0		31.4		24.2		34.2		27.6		24.2	
Pyrope	1.0		-		-		0.6		0.8		5.3	

	10 MLA		11 MLA		12 MLA		13 MLA		14 MLA	
SiO_2	34.55		34.34		34.52		34.31		34.60	
TiO_2	1.49		1.52		1.31		1.47		1.20	
Al_2O_3	13.09		12.28		12.17		10.74		12.09	
Cr_2O_3	10.33		11.39		11.61		13.66		12.18	
CaO	39.34		39.35		39.46		38.97		39.37	
MgO	0.51		0.36		0.25		0.24		0.15	
$FeO_{(TOT)}$	0.68		0.76		0.67		0.61		0.41	
Total	100.01		100.00		99.99		100.00		100.00	
Ca^{2+}	3.096		3.111		3.122		3.107		3.119	
Fe^{2+}	-	3.16	-	3.15	-	3.15	-	3.14	-	3.14
Mg^{2+}	0.060		0.042		0.030		0.029		0.018	
Al^{3+}	1.253		1.186		1.176		1.052		1.169	
Cr^{3+}	0.622	2.01	0.689	2.01	0.703	2.00	0.834	2.01	0.738	2.01
Ti^{4+}	0.090		0.092		0.079		0.090		0.073	
Fe^{3+}	0.042		0.047		0.042		0.038		0.026	
Si^{4+}	2.838	2.84	2.833	2.83	2.848	2.85	2.850	2.85	2.858	2.86
Al^{3+}	-		-		-		-		-	
Uvarovite	31.5		32.7		35.0		42.0		37.5	
Andradite	6.0		6.6		6.0		6.0		6.0	
Grossular	61.5		59.3		58.0		51.0		56.0	
Pyrope	1.5		1.3		1.0		1.0		0.5	

End member analyses calculated according to Deer et al, 1982 1A:482

TABLE 4
Uvarovite Analyses From Other Localities (weight %)

	1		2		3		5		6	
Reference	a (3)		a (4)		a (6)		b (4)		b (6)	
SiO_2	36.25		37.31		32.44		38.65		38.02	
TiO_2	1.07		-		0.07		0.52		0.40	
Al_2O_3	3.76		5.34		8.90		12.20		10.49	
Cr_2O_3	22.57		22.60		21.96		12.76		14.04	
CaO	34.28		34.25		18.82		21.07		23.86	
MgO	0.34		0.25		13.02		8.88		6.61	
MnO	0.03		0.15		0.05		0.35		0.37	
$FeO_{(TOT)}$	1.03		0.30		1.87		5.38		5.85	
Total	100.10		100.20		100.01		99.81		99.64	
Number of ions on the basis of 24 (O)										
Mg^{2+}	0.042		0.030		1.562		1.019		0.772	
Fe^{2+}	-	3.10	-	3.01	0.037	1.94	0.226	3.01	0.203	3.00
Mn^{2+}	0.056		0.011		0.004		0.023		0.025	
Ca^{2+}	3.004		2.965		1.623		1.738		2.002	
Al^{3+}	0.327		0.509		0.455		1.081		0.945	
Cr^{3+}	1.459	1.92	1.444	1.97	1.397	3.23	0.777	2.00	0.869	2.00
Fe^{3+}	0.064		0.018		0.081		0.108		0.162	
Ti^{4+}	0.066		-		0.004		0.030		0.024	
Si^{4+}	2.964	3.00	3.014	3.01	2.611	3.00	2.975	3.00	2.977	3.00
Al^{3+}	0.036		-		0.390		0.026		0.023	
Almandine	-		-		-		6.97		6.70	
Andradite	3.4		0.9		-		5.02		7.37	
Grossular	15.8		24.4		-		13.75		15.18	
Knorringite	-		-		18.1		-		-	
Pyrope	1.5		1.0		19.7		34.10		25.72	
Spessartine	1.9		0.3		-		0.76		0.82	
Uvarovite	77.4		73.3		62.2		38.99		43.47	

	7		8	
Reference	c (6)		c (10)	
SiO_2	36.86		34.52	
TiO_2	0.40		1.68	
Al_2O_3	8.98		8.05	
Cr_2O_3	11.54		14.83	
CaO	35.93		32.81	
MgO	0.62		1.86	
MnO	-		0.03	
$FeO_{(TOT)}$	5.14		6.33	
Total	99.47		100.22	
Number of ions on the basis of 24 (O)				
Mg^{2+}	-		0.147	
Fe^{2+}	-	3.40	-	3.22
Mn^{2+}	-		-	
Ca^{2+}	3.402		3.077	
Al^{3+}	0.628		-	
Cr^{3+}	1.044	2.23	1.328	2.10
Fe^{3+}	0.528		0.644	
Ti^{4+}	0.032		0.132	
Si^{4+}	2.276	2.28	2.111	2.67
Al^{3+}	-		0.558	
Almandine	-		-	
Andradite	28.0		20.6	
Grossular	33.2		15.6	
Knorringite	-		-	
Pyrope	-		4.9	
Spessartine	-		-	
Uvarovite	52.2		66.4	

References

a Deer et. al., 1982
(3) Uvarovite, South Ham, Wolfe County Quebec (Dunn, 1978) (podiform chromitite body)
(4) Uvarovite-diopside-tremolite skarn Outokumpu, Finland (Knorring, 1951) (this deposit has recently been interpreted as an ophiolite complex with contained podiform chromitite bodies, Vuollo et al, 1993)
(6) Uvarovite from Kämmererite-Uvarovite vein in chromitite ore Kalrangi Mines, Orissa India (Chakraborty, 1968)
(11) Uvarovite from a kimberlite pipe, Newlands 60km NW of Kimberley South Africa (Clarke and Carswell, 1977)

b Clarke and Carswell, 1977 (kimberlites from South Africa)

c Frankel, 1959 (layered chromitites from the Bushveld Complex of South Africa)
(6) Derdegelid, 141 Lydenburg District
(10) Doornbosch, 423 Lydenburg District

4 Analysis not used

Comparison with uvarovite garnets from various world localities

Table 2 lists the physical properties of these chromian garnets along with those of other occurrences. The unit cell size of the MLA garnets are similar to those of Frankel's (1959) No.5 garnets whereas the unit cell size for the Fontenoy garnets is in between that of the theoretical end-member and Frankel's (1959) No.10 garnets. The average RI value of the garnets from both deposits is closest to the theoretical uvarovite end-member.

Looking at the Cr_2O_3 contents, neither the Fontenoy nor MLA garnets are close to the theoretical end-member. The Fontenoy garnets are similar to analysis 2 of von Knorring (1951) whereas the MLA garnets are closest to analysis 5 of Frankel (1959). There is no clear relationship between the Cr_2O_3 content of the garnets and the unit cell size of these garnets unlike that reported by Frankel (1959).

Uvarovite garnets from various world localities were chosen for their different tectonic/genetic settings and their analyses are presented in Table 4. One can see that they vary widely in composition with the variability being most pronounced within the oxides TiO_2, Al_2O_3, Cr_2O_3, CaO, MgO and FeO $_{(Total\ Fe)}$.

The uvarovite occurrences can be grouped into the following:

(a) podiform chromitite bodies

(b) meta-ophiolite bodies

(c) kimberlite pipes

(d) layered chromitites

If we plot the analyses from Table 4 on to the Al^{3+}-Cr^{3+}-Fe^{3+} triangular diagram (Figure 2), we find that the uvarovites from the different groups described above fall into discrete fields on the triangle, with the exception of the podiform chromitites and meta-ophiolites (which fall into the same field) and the uvarovites from the layered chromitites which do not fall into a discrete field on this triangle. Thus, based on this small number of analyses, one can see that uvarovite garnets which occur in rocks that have formed in distinctly different tectonic/genetic environments are compositionally different.

From the analyses (Table 4), we can see that the uvarovite garnets from both podiform chromitites and metaophiolites have highly restricted Cr_2O_3 contents of approx. 22-23%. With the exception of FeO $_{(Total\ Fe)}$, analyses 1 and 2 are almost identical. Analysis 3 varies from the other two in having less SiO_2 and CaO but more Al_2O_3, MgO and FeO $_{(Total\ Fe)}$.

Both garnets from kimberlite pipes have very similar compositions to each other, and have quite high Al_2O_3 (10.49 and 12.20 Wt%) and FeO $_{(Total\ Fe)}$ (6.61 and 8.88 Wt%). Those from the Bushveld layered chromitites also have very similar compositions to each other (though distinctly different from the other occurrences), with moderate Al_2O_3 (8.98 and 8.05 Wt%) and quite high FeO $_{(Total\ Fe)}$.

From their analyses (Table 3) and position on the Al^{3+}-Cr^{3+}-Fe^{3+} triangular diagram (Figure 2), the uvarovite garnets from the Fontenoy deposit are most like those from the layered chromitites of the Bushveld Complex although the tectonic environment of the rocks that they occur within is the same as those from the podiform chromitites. The chromian grossulars from the MLA deposit are distinct from all of the other garnet analyses presented. They have similar Al_2O_3 and Cr_2O_3 concentrations to the uvarovites from kimberlite pipes but much higher CaO and significantly lower FeO $_{(Total\ Fe)}$. However, on the Al^{3+}-Cr^{3+}-Fe^{3+} triangular diagram, they fall very close to the field for the uvarovites from kimberlite pipes in South Africa.

Compared to the uvarovite garnets from the podiform chromitite deposits and metaophiolites (which occur in rocks that have formed in similar tectonic/genetic environments to those of the MLA and Fontenoy garnets), those from the Fontenoy deposit contain significantly less Cr_2O_3 and MgO, but significantly higher TiO_2, CaO and FeO $_{(Total\ Fe)}$. Those from the MLA deposit have significantly less Cr_2O_3 and FeO $_{(Total\ Fe)}$ but much higher TiO_2, Al_2O_3 and CaO.

Comparison and effectiveness of the two techniques

Winchell (1958) constructed determination charts relating chemical composition (in terms of end member molecular proportions) with unit cell size and refractive index. He constructed two triangular charts, one with pyrope, almandine and grossular and the other with grossular, almandine and andradite as end members. It was intended to examine the validity of using this physical method of determining end member molecular proportions with end member molecular proportions determined chemically from microprobe analyses. An appropriate chart would have andradite, grossular and uvarovite as end members. Unfortunatly the value of the unit cell size of andradite (12.048 Å) and uvarovite (11.996 Å) are too close to make this method practical.

In the ternary system of andradite ($Ca_3Fe_2^{3+}Si_3O_{12}$); uvarovite ($Ca_3Cr_2^{3+}Si_3O_{12}$) and grossular ($Ca_3Al_2^{3+}Si_3O_{12}$) there is substitution between the trivalent cations Fe^{3+} (0.64 Å), Cr^{3+} (0.63 Å) and Al^{3+} (0.51 Å). Since the ionic radii of Fe^{3+} and Cr^{3+} are similar, substitution of these cations for Al^{3+} would expand the lattice in a similar way. Thus, a graph of unit cell size versus Cr^{3+}+Fe^{3+} should be approximately linear.

Although the combination of unit cell size and refractive index measurements for the garnets from both the MLA and Fontenoy deposits point to them as being the species uvarovite, the SEM analyses show that the Fontenoy garnets are in fact true uvarovite garnets whereas those from the MLA deposit cannot be termed uvarovite as the grossular molecule is the dominant garnet molecule present and they therefore should be termed chromian grossular garnets.

FORMATION OF UVAROVITE

General statement

In order to explain the formation of both garnet occurences, the following facts must be taken into account:

1) Rarity and localised occurrence.
2) Restriction to podiform chromitite bodies.
3) Fracture-fill occurrence.
4) Association with chromian clinochlore.
5) Spacial association of the MLA garnets with a metasomatite dyke and rodingite bodies.
6) Spatial association of the Fontenoy garnets with diopside-clinochlore rocks.
7) Differing chemistry of the garnets between the two deposits.

The rarity and localised occurrence of the garnets suggests that the conditions required for their formation are only rarely met in nature. Although the CSB contains over 50 podiform chromitite deposits, chromian garnets have to date only been found within two of them (The MLA and Kangaroo East Mines), both cases, of rare occurence.

All of the chromian garnets found occur within podiform chromitite bodies. This suggests that the chromium for their formation is derived from chromite within the podiform chromitite bodies and not from either accessory chromite grains or chromium-bearing silicates from within the partially serpentinised harzburgite hostrock. Thus, during the formation of the chromium-bearing garnets, chromium from within the chromitite must have been at least locally remobilised (Franklin *et al*, 1992) and then incorporated within the garnet molecule during its growth. Other components required for the formation of the garnets (such as Al, Mg and Fe) may have also been released from the chromite grains at this time.

As the chromian garnets occur as a fracture-fill assemblage within the chromitite ore, they must postdate the formation and solidification of the podiform chromitite bodies and are therefore not likely to have formed within the initial magmatic environment of formation of the podiform chromitite deposits (Graham *et al*, in press). Both field and scanning electron microscope observations suggest that they have in fact formed at the onset of serpentinisation during a period of rodingitisation (Calcium metasomatism with Ca being released from Ca-rich diopsidic clinopyroxenes in the host harzburgite and being subsequently concentrated within intrusive gabbroic dykes (now rodingites) (Graham *et al.* 1994).

The association of the chromian garnets with chromian clinochlore suggests that these two minerals were cogenetic and also points to a hydrothermal source for the formation of the garnets.
The chromian grossular occurence at the MLA mine is spatially associated with a metasomatite dyke (consisting of the minerals albite, biotite, prehnite, vermiculite and pyrophyllite) and various rodingite dykes (composed of various proportions of grossular, prehnite, zoisite, vesuvianite, diopside and vermiculite) while those from the Fontenoy deposit are associated with diopside-chromian clinochlore rocks. Thus, both occurrences of chromian garnets are associated with rocktypes which contain the nesessary components, other than chromium which is derived from the chromitites, for their formation.

Although both of them occur within podiform chromitite bodies, the chromian garnets that are found at the two deposits are distinctly different in their composition. Also, within the one deposit, the composition of the chromian garnets tends to be very similar. Therefore, there must be a local factor controlling the composition of the garnets formed.

Uvarovite formation

Clarke and Carswell (1977) stated that a high Cr^{3+}/R^{3+} ratio is needed in the environment of formation of uvarovite garnet. Thus, the Cr^{3+} ion must be available in the environment of formation of uvarovite. As the chromian garnet occurrences in this study are restricted to the podiform chromitite deposits, the obvious source for the chromium within the garnets is the chromite from within the deposits. Von Knorring (1951) noted that chromite inclusions in uvarovite are common and that the first generation of uvarovite was a replacement product of original chromite grains. Also, Frankel (1959) noted that within the Bushveld Complex of South Africa, all of the uvarovite occurrences were restricted to the chromitite seams and that uvarovite formation is entirely dependent on the presence of adequate amounts of chromium. For chromium to be released from the chromite grains during the formation of uvarovite, the chromite grains have to be both physically and chemically "broken-down" in order to at least locally remobilise chromium. Such localised remobilisation of chromium within the CSB was reported by Graham *et al*, (1994).

The chromium garnets described in this paper were all found within the fracture-fill assemblages of the host chromitites. A similar fracture-fill occurence was reported from Orissa, India, by Mitras (1973). Thus, uvarovite clearly postdates the formation of chromite from which some of its components are derived.

Experimental data (Huckenholz (1975), Huckenholz and Knittel (1975), Clarke and Carswell (1977)) showed that uvarovite garnet is derived from a host rock rich in both Cr and Ca; there is a complete solid solution series between uvarovite and grossular at temperatures below 855 +-5^{o}C; and that uvarovite forms at subsolidus temperatures through the breakdown of a primary clinopyroxene-spinel assemblage.

Clarke and Caswell (1977), showed that the Cr/Al ratio in uvarovite increases with pressure. It is possible that the

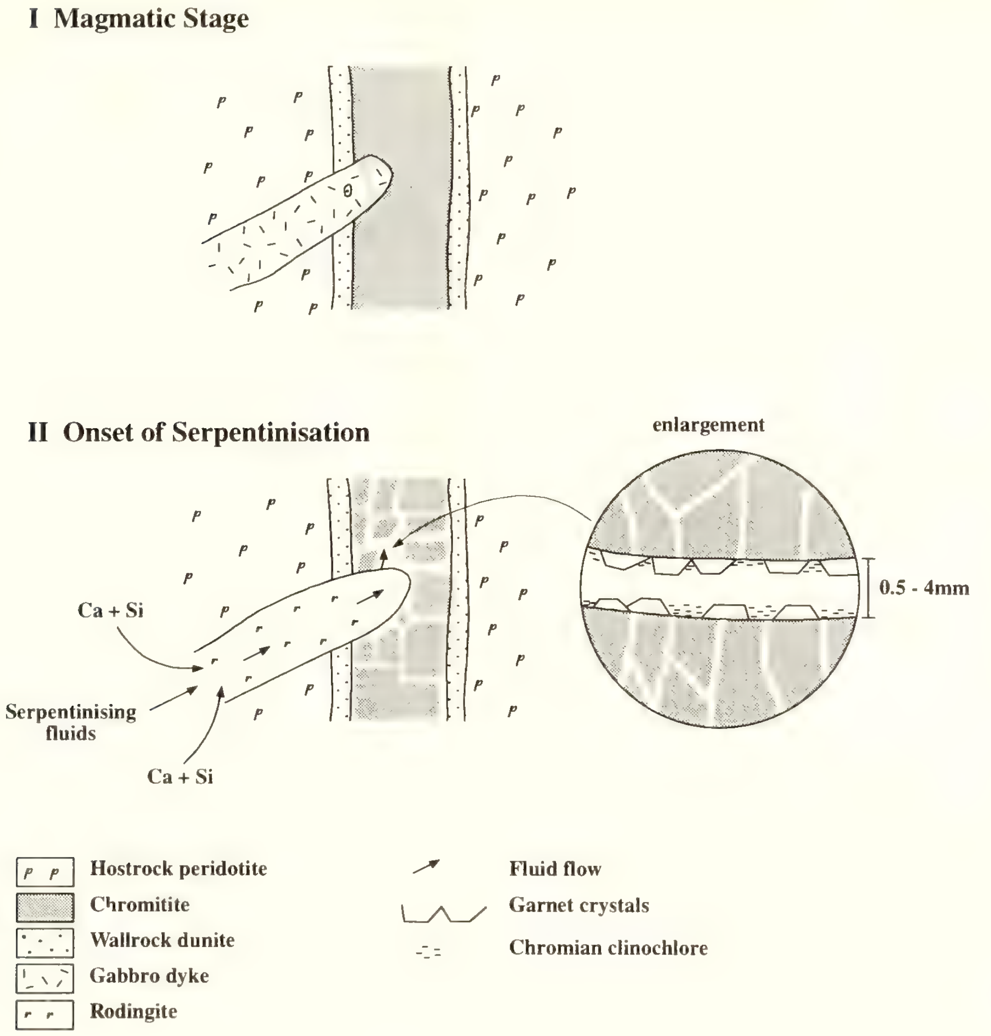

Figure 3. Sketch diagram showing the formation of uvarovite

Fontenoy garnets (which are uvarovite garnets) formed under conditions of higher pressure than the MLA garnets (which are chromian grossulars) as the metamorphic grade of the WSB is significantly higher than that of the CSB. This is expressed in the serpentine-group minerals of the belts as antigorite is the dominant species in the WSB whereas the CSB almost exclusively contains lizardite-chrysotile assemblages. However, the differing Cr/Al ratio of the garnets could also simply be due to the fact that the Fontenoy garnets are associated with Cr-rich chromite whereas the MLA garnets are associated with Al-rich chromite. Thus, during serpentinisation, more Cr was available for localised remobilisation in the Fontenoy deposit compared to that available in the MLA deposit.

It is certainly apparent that the differing Cr/Al ratios in uvarovite reflects the primary chromite host composition and this composition would almost certainly seem to be the controlling factor in the formation of uvarovite. Another important factor is the availability of Ca in the localised environment during the serpentinisation process. Huckenholz and Knittel (1975) have shown that Ca substitutes for both Mg^{2+} and Fe^{2+} in the 8-fold position, during the formation of uvarovite. This would explain the occurence of both andradite and pyrope molecules in the Fontenoy garnets and the absence of them in the MLA garnets which are chromian grossulars that are unusually Ca-rich and contain negligible Mg^{2+} and Fe^{2+}. Thus, during their formation, excess Ca was available for the MLA garnets but not for the Fontenoy garnets. The actual amount of Ca available for garnet growth in this environment of formation may well be controlled by either the original composition of the host peridotite and/or the T-P conditions at the time of their formation.

Thus, like Frankel (1959) and Mitras (1973), we would say that the formation of uvarovite garnets is due to calcium (or lime) metasomatism and that the chromium required for their formation is released from local chromite enrichments (i.e chromitites) during this process which would seem to occur at the onset of the serpentinisation process (Graham *et al*, 1991). This process is best shown diagramatically in Figure 3.

CONCLUSIONS

Unit cell size measurements combined with refractive index measurements are not sufficient to distinguish between uvarovite and chromian grossular. The only accurate way to determine the dominant garnet molecule present is to analyse the garnet (in the case of this study, by using a scanning electron microscope) as solid solution between the uvarovite and grossular end-members is pervasive. This is also possibly true for all of the other garnet species.

The chromian garnets from southeastern NSW formed during

the onset of the serpentinisation process by calcium metasomatism and localised chromium remobilisation from the adjacent podiform chromitite bodies.

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A CENTURY OF X-RAYS

Proceedings of a half-day seminar commemorating Professor Röntgen's discovery of X-rays in 1895

Editors' Foreword

Some inventions and discoveries strike the popular imagination more than others. The announcement of the discovery of a new, utterly mysterious radiation, revealing what had so far been absolutely hidden from human eyes —not least the bones and organs in living men, women and children — caused a sensation which our blasé age would find it hard to duplicate.

The discovery was made by Wilhelm Conrad Röntgen (1845-1923), Professor of Physics at the University of Würzburg, then a smallish town in south-west Germany. Although it happened at a time when many astonishing inventions and discoveries in physics, chemistry and engineering were appearing, Röntgen's discovery of these mysteriously penetrating rays and what could be done with them, provoked a sense of wonder not unmixed with uneasiness.

The centenary of Röntgen's discovery is worthily commemorated all around the world. However, most of these functions are directed to members of scientific and other professional societies. The following six papers were contributed to a Seminar commemorating Röntgen's discovery and recalling its numerous consequences in almost every field of human endeavour. The addresses given at the Seminar and reported in these proceedings were directed primarily to members of the general public, and this did not happen by chance.

In recent years there had been increasing public awareness of negative sides of scientific activities. The innumerable ways in which science and scientific technology have made life more secure and more comfortable are often taken for granted. On the surface, and most of us rarely see or are able to see below the surface of scientific achievements, everything appears clear and simple like pictures on a television screen. The complex physics behind the screen is quietly overlooked.

As it happened, Röntgen's discovery began with a fluorescent screen which had much in common with today's TV screens. But that was only the beginning. A consideration of how Röntgen rays became, over the years, indispensable tools in innumerable spheres of human activity was thought to offer a welcome opportunity to stimulate interest in some of the science behind the TV screen. The Seminar was organised with this opportunity in mind.

It is still necessary to add a few words about Röntgen the man. When he made his path breaking discovery he was no longer young but in his 51st year — an age when he might have welcomed this chance to start a new career which had every prospect of leading to fame and fortune beyond the dreams of avarice.

None of this happened. On December 28, 1895, he announced his discovery to the members of the Physical-Medical Society of Würzburg in a sober and cautiously worded publication. Over the next few years he published two or three more papers on his discovery, but that was all. He left it to younger men to follow up what he had initiated, which was done with a vengeance. By December 1896, just a year after the first announcement, more than a thousand papers had been published seeking to elucidate phenomena which were to remain inexplicable for over 15 years.

Röntgen received innumerable invitations to demonstrate his discoveries from men of distinction in all walks of life. He declined in almost every case, though he did demonstrate the powers of his mysterious rays to the German Emperor in a special audience. He received the Nobel Prize in Physics for 1901, the first year in which this coveted distinction was awarded, but he refused to patent his discovery, not wishing to impede the spread of an innovation with the potential to benefit vast

numbers of people everywhere. He refused numerous other opportunities to gain material advantage from what he had done.

To Röntgen, and to many other scientists before and since, the certainty of having added to knowledge about the world was all the reward they sought and found. He died in 1923 in poverty and ill health in his 78th year, but we have reason to be confident that he had the satisfaction of knowing that he was leaving a heritage of achievement which few would or could have equalled.

However, there is another side to all human activities. It was Röntgen's even more famous countryman, the great German poet Johann Wolfgang von Goethe, who raised this other side over a hundred years before the coming of Röntgen rays. Goethe took a very different view of the benefits to be expected from a growth of knowledge about the world around us, and this has not been overlooked in what follows.

The papers presented at the Seminar are reprinted here to introduce readers to the vast extent of Röntgen's heritage, demonstrating that it touches our lives in many more ways than is commonly realised. We hope that these contributions will not only encourage a balanced appreciation of scientific activities, but also stimulate a continuing interest in their rich history.

W.R. Albury
G.C. Lowenthal

A Century of Röntgen Rays

E.A. Booth

Mr Chairman, Ladies and Gentlemen:

Some thirty years ago I was invited to speak at a dinner arranged by the Medical Society of the University of New South Wales. A short time before, there had been the first Conferring of Degrees of the Faculty of Medicine from this University, when its main address had been given by Sir Macfarlane Burnet. During my speech at that dinner I endeavoured to make the point that the end of the medical course was only the beginning of one's medical career, and I stressed the need to develop an inquiring mind. About a hundred years ago Wilhelm Conrad Röntgen did just that.

At that time, it had been shown that something happened when a large electric current was transmitted from the cathode to the anode of a glass tube from which air had been evacuated. It had been found that certain chemicals fluoresced on these occasions.

Holding a piece of material coated with one of these chemicals near such an energised tube Röntgen saw the bones of the fingers stripped of their flesh. One can imagine his excitement. However, being a true scientist he went on to produce many papers to elucidate these mysterious, unknown X-rays.

There have been other similar discoveries such as penicillin (Fleming), smallpox vaccination (Jenner), etc. Scientists asked "Why is it so?" as Professor Sumner Miller used to do, and proceeded to find an answer.

I am reminded of the prayer of Maimonides, the medieval physician and philosopher, "In all things let me be content — in all but the great science of my calling. Let the thought never arise that I have attained to enough knowledge; but vouchsafe to me ever the strength, the leisure, and the eagerness to add to what I know. For art is great and the mind of a man ever growing".

We are here today to celebrate a century of Röntgen rays — the 100th anniversary of Röntgen's discovery. It is a momentous occasion and although there have been such great changes in our knowledge and use of X-rays, it all began when Röntgen sought an answer — "Why is it so?"

We all do well to remember this great man and the benefits that have followed his wonderful discovery. I am sure we are all most grateful

to the organisers and sponsors of this seminar, which I now have much pleasure in declaring "open".

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The Discovery of X-Rays and its Immediate Impact

J. Ryan

Abstract: Professor Röntgen called the rays he had discovered X-rays because their origin was a deep mystery to him and it did remain unexplained for another 15 years. He spent seven weeks following his discovery working intensely in his laboratory to clarify as many of the characteristics of these mysterious rays as was then possible before announcing his discovery on 28th December 1895, to experience, within days, a sensationalism of press reporters that was no less strident in 1895 than it is at present. Another lesson came when he had to defend his priority to the discovery against jealous colleagues. X-ray applications expanded rapidly all around the globe and not only in medicine. The news of Röntgen's discovery arrived in Australia during the first days of January 1896. Subsequent early developments in this country will be described in some detail.

When Röntgen announced the discovery of X-rays at the end of December, 1895, one of the illustrative images he displayed to the Physical-Medical Society of Würzburg was a picture of his wife's hand, showing the bones of her hand and wrist with her wedding ring on her fourth finger. Seeing this X-ray was disturbing to Bertha, as it was the first time that a skeleton had been seen in a living person, and she felt distressed by the phenomenon.

After presenting his paper Röntgen wrote to a number of colleagues in the world of physics to tell them of his results, giving full details of his work so that they could easily replicate it and confirm his experiment. Within a very short time, the news of his discovery had been sent around the world. This was done mainly in the newspapers of the day, and it was then that Röntgen discovered that the lay press is not the optimal means of communicating scientific information, since there were many wild and inaccurate observations made about these new rays. So much so that "X-ray proof" clothes were advertised for sale, legislation against "X-ray opera glasses" was proposed (to protect the modesty of stage performers and those sitting near the stage) and photographers offered special photographic effects using the new technique. This was Röntgen's first lesson.

After he announced his discovery, there was considerable discussion as to whether he had in fact been the first to produce X-rays, and several others claimed priority. There is no doubt that X-rays had been produced in many laboratories before November, 1895, as there are many stories of photographic film being spoiled when it was kept near Crookes' tubes as currents were passed through them. One well documented case is of Morris Wilbur Stine, a New York physicist, who noted that he had produced his first "skiagraph" in February, 1892. Arthur Willis Goodspeed specified that he had obtained actual images of metallic

objects in the winter of 1890, but he specifically denied any claim to priority, because he had failed to interpret these shadows and had not recognised the cause of the images on the photographic plate.

The most bitter claimant to priority was the German physicist Philipp Lenard, who had described the penetration of "cathode rays" through aluminium. When Röntgen announced his discovery, Lenard congratulated him in a letter, referring to "your great discovery", to which Röntgen replied, acknowledging the work of Lenard and his teacher Hertz in his Würzburg lecture. However, when Röntgen was awarded the first Nobel prize for physics in 1901, Lenard felt great animosity toward Röntgen, as he felt that he should have shared in the prize. This was Röntgen's second lesson.

Röntgen was invited to demonstrate his discovery to the Kaiser on 13th January, 1896. Amongst those present was the surgeon-general of the German Army, General Leuthold, who expressed interest in the possible military applications of the new technique. This thought was prophetic, since amongst the first applications of X-rays were examinations of war casualties, in particular diagnosing the extent of fractures and locating metallic foreign bodies. At this demonstration, Röntgen was awarded the Royal Order of Merit of the Bavarian Crown, which carried with it personal nobility.

The importance to the military of diagnosis by X-ray is shown by the fact that many of the 622,000 deaths that occurred in the American Civil War were caused by the treatment of injuries when inadequate diagnosis made amputation a frequent occurrence in the treatment of gun shot and bomb blast wounds. The position and severity of fractures and the sites of foreign bodies could only be assessed clinically, by palpation.

The first recorded military use of X-rays was by an Italian, Lieutenant Giuseppe Alvaro, at the military hospital in Naples. After the battle of Adowa, in (then) Abyssinia on 1st March, 1896, two casualties were radiographed to localise fragments of shrapnel in their forearms, when all clinical efforts had failed to find the small pieces of metal. In the Graeco-Turkish war of 1897, the German Red Cross provided a hospital unit to support the Turkish army in Constantinople, complete with an X-ray apparatus supplied by the British Red Cross. The batteries of H.M.S. Rodney were used to recharge the unit. In 1897, in the Tirah campaign fought near the Khyber Pass, the British Surgeon-Major Beevor used X-ray apparatus in assessing casualties. In 1899, Surgeon-Major Battersby wrote: "Radiography can boast its most brilliant results in obscure injuries to bone, particularly when the injured parts are too swollen to admit of careful examination by ordinary methods, or when such examination cannot be borne by the patient."

Other military uses of X-rays were reported from the battle of Omduram in the Sudan and from the Spanish-American war of 1898, the first reported use of X-rays in a military context in the western hemisphere. During the Boer War (1899-1902) field issue British Army X-ray equipment was supplied to all general hospitals.

Long before these military applications of radiography, there had been numerous instances of other medical uses of X-rays. A prescient letter by Arthur Schuster, Professor of Physics at Manchester University published on 11th January, 1896, in the *British Medical Journal* stated: "....there can be no doubt that a most important discovery has been made. It is not necessary to enter into the many possible medical applications that this photograph [of Frau Röntgen's hand] open out."

Although there were many demonstrations of X-rays as a kind of parlour trick in 1896, most of the work carried out was done by serious medical experimenters seeking ways in which X-rays could be used for diagnostic purposes. To begin with, this consisted of demonstrating foreign bodies, and then fractures were shown, in addition to bone pathology. The first medical radiologist was Sidney Donville Rowland, in Great Britain, who was regularly examining patients from February, 1896. In the *British Medical Journal* of 22 February, 1896, the surgeon Bertram Leonard Adams described the surgical removal of a post traumatic spur from the little finger of one of his patients, the preliminary X-ray being taken by Rowland.

Diagnostic radiology was thus born and soon was being practised throughout the world, as

news of the discovery was reported. In Australia, the first press reports were published in several daily newspapers on 31st January, 1896, but it was not until the next month that details of the method were available. There were at the time numerous people, mainly physicists, who had access to Crookes' tubes and the other apparatus required to produce X-rays. They immediately set out to duplicate the experiment, and it was not long before many examinations were being performed. There is, probably inevitably, discussion and conjecture as to who actually was the first to use X-rays in Australia. The following list of published reports suggests that Professor Thomas Ranken Lyle of the University of Melbourne preceded the others, but there are conflicting claims. A letter from the grandson of Dr. F.J. Clendinnen in the Archives of the College of Radiologists suggest that Clendinnen had, in fact, discovered X-rays before Röntgen, but that communication delays prevented him announcing this before the report of Röntgen's work was published in Australia in January, 1896.

- 4th March, 1896, the Melbourne *Argus* published a radiogram of a foot taken by Professor Lyle.
- 16th May, 1896, the *Australasian* published a radiograph of a rat taken by Mr. G.W. Selby.
- 28th May, 1896, the South Australian *Register* reported that Mr. Barbour and Professor William Bragg had taken an X-ray of a hand.
- 13th June, 1896, the *Australasian* published a radiograph of a flounder, taken by Dr. F.J. Clendinnen.
- 27th July, 1896, the Ballarat *Free Press* reported successful surgery on the hand of Eric Thompson after a gun shot injury was shown in an X-ray taken by Father Joseph Slattery at St. Stanislaus' College, Bathurst.

The accepted three Australian pioneers in radiology are Father Joseph Slattery in Bathurst, Walter Drowley Filmer in Newcastle and Thomas Ranken Lyle in Melbourne. One of Filmer's sons, Roy, claims that his father produced X-rays within two days of the details of the discovery being published, presumably on 15th February, 1896. (There was insufficient detail published in Australia before this.) These X-rays showed and located a broken needle in a patient's foot. Another son, Walter, claimed that his father had radiographed his (Walter's) hand prior to that.

There were many others who took X-rays in the first half of 1896, but after this time much of the unpublished information must be taken with care. There is no doubt, however, that the first practising radiologist in Australia was Dr Frederick John Clendinnen of Melbourne, and he was also the first medical practitioner to X-ray a patient, on 22nd May, 1896.

It is evident that the immediate impact of the discovery of X-rays was in the investigation and assessment of trauma, in particular the diagnosis of fractures and the location of foreign bodies, usually metallic, but glass foreign bodies were also demonstrated. Other diagnostic uses were applied from an early date. On 24th April, 1896, William Morton read a paper on dental radiography to the New York Odontological Society, presenting radiographs of the roots of teeth, fillings and diseases of the adjacent bones. Also in 1896, William Rollins of Boston devised an intraoral film for dental radiography. The first dental radiograph in Australia was produced by F.J. Clendinnen.

Radiotherapy also became useful very soon after Röntgen's discovery was made known. To begin with, the use of X-rays was quite empirical, in the spirit of "Let us see what these new rays will do." For this reason, skin lesions were first treated, as they were visible and any effects could be seen and evaluated. In March, 1896, John Daniel, a physicist at Vanderbilt University in Tennessee, reported that an unexpected side effect of radiation was to cause the hair to fall out. This conclusion was reached when X-rays were taken of a child's head after he was accidentally shot. Partial shielding was carried out, to avoid scattered radiation degrading the film. Twenty one days after the X-rays were taken, the child's hair fell out, but only from the part of the scalp that had been irradiated. The protected part of the scalp retained its hair and was quite unaffected. The conclusion drawn from this accidental experiment was that living tissue was sensitive to radiation. Epilation in the treatment of ring worm became popular, using radiation. Acne also was successfully treated, as was lupus vulgaris, and it was not long before skin cancers were irradiated, with success.

Radiotherapy had been carried out for skin diseases in Australia for some time, and in 1896, Dr Cleaver Woods of Albury used radiation to attempt a cure of a carcinoma of the larynx, with only limited success. This was one of the first uses of radiotherapy in Australia for cancer not of the skin. When radium became available, radium therapy and X-ray therapy were instituted in most hospitals in the capital cities, in addition to numerous private practices. Over the five or ten years from the discovery of X-rays, the uses of diagnostic and therapeutic radiology were extended at a rapid rate. By 1900, kidney stones and gall stones had been demonstrated, and vessels had been shown in X-ray images with the use of opaque material, usually on cadavers, as a safe contrast was not available for routine clinical work. Some *in vivo* arteriograms and venograms were made, using soluble bismuth salts in very low doses.

The early history of radiology is replete with tales of priority disputes, of empirical discoveries and ever-expanding applications of this new kind of ray. The discovery of X-rays by Röntgen opened up new worlds of diagnostic possibilities, and Röntgen ranks with Vesalius, Lister, Pasteur and Koch in the unending story of the development of medical science from Hippocrates to the present day.

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Roentgen's X-Rays, A Pioneering Discovery for the Development of 20th Century Physics

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Abstract: Röntgen's 1895 discovery was the culmination of centuries of observation and experimentation in electricity and magnetism. The magnetic properties of amber (a Baltic fossil resin) were discovered by the Greeks 2,500 years ago. Sailors in the Mediterranean for thousands of years had used Lodestone, a naturally occurring magnetic ore as a primitive form of compass. The observation that friction caused amber to attract light objects and the ability of Lodestone to attract ore led to the first scientific study of this phenomenon. In addition to electricity and magnetism, the third major physical principle involved in X-ray production is the vacuum and the evacuated glass tube. This occurred in the 19th century with the development of the Crookes tube. It was Röntgen's ability to both synthesise the scientific work

that had gone before him and make the forward leap to postulate the existent of a new form of ray that was the hallmark of his genius. Nevertheless, Röntgen's discovery in itself was simply part of an evolving spectrum of scientific discovery which subsequently resulted in the discovery of radioactivity, the development of nuclear energy and (regrettably) nuclear weaponry.

"In the history of science, nothing is more true than that the discoverer, even the greatest discoverer, is but the descendent of his scientific forefathers; he is always essentially the product of the age in which he is born."
Sylvanus P. Thompson, 1897
(Eisenberg, 1992: 3)

Roentgen's 1895 discovery was the culmination of centuries of observation and experimentation in electricity and magnetism. Some 2,500 years ago the Greeks discovered the electric properties of amber — a Baltic fossil resin. From earliest times the use of Lodestone — a naturally occurring magnetic ore — as a primitive compass was widely practised.

Four hundred years ago the analogy of amber attracting light objects and the lodestone attracting iron led to the first scientific study of the phenomenon. Anticipating Newton's theory of gravitation, William Gilbert postulated that all bodies in the vicinity of the earth are attracted to the great mass of the earth. His *De Magnete* (Gilbert, 1600) formed the scientific foundation for subsequent investigations of electricity and magnetism. "All of my experiments were repeated again and again under my own eyes", he wrote, and his comment was echoed by Röntgen 295 years later.

In addition to electricity and magnetism, the third major physical prerequisite for X-ray production is the vacuum and the evacuated glass tube. The development of the Crookes' tube and identification of cathode rays (electrons) fulfilled this requirement.

When using tubes with a vacuum raised to a millionth of an atmosphere, Crookes unknowingly was generating X-rays and he found that photographic plates in unopened boxes were strangely fogged and blackened. When he complained to the manufacturer, Ilford, he was initially sent replacements — and Ilford later suggested that the damage was occurring in his own institution.

Crookes was not the first to produce X-rays unknowingly. In 1785 William Morgan experimented with electricity in a vacuum. In the course of his experiments, the tube cracked and admitted air. Morgan observed a succession of beautiful colours — beginning with yellowish green and passing through blue and purple to red. After Röntgen's discovery the identification of the yellow-green shade with X-rays made it clear that Morgan had produced them.

At the same time, the Scottish physicist James Clerk Maxwell interpreted Michael Faraday's work in terms of higher mathematics to form the electromagnetic theory of light — a theoretical prediction of the existence of X-rays.

Maxwell's theories in turn influenced Hermann von Helmholtz — the mathematical discoverer of X-rays. In his "dispersal theory of the spectrum" he allowed for X-rays and radio waves, specifying properties that included the ability to pass through opaque material. Helmholtz's pupil, Heinrich Hertz, was assigned the task of producing these waves in the laboratory.

The theories of Helmholtz led Sir Oliver Lodge and Sir Joseph John Thompson to conclude, only eight months after Röntgen's discovery (but fifteen years before it was experimentally proven) that X-rays belonged to the short-wave end of the light spectrum.

In 1887 Hertz discovered wireless or radio waves. He then discovered that cathode rays would pass through a thin film of aluminium placed within the tube. This led Philipp Lenard to study the effects of cathode rays on fluorescing substances such as phosphates and ketones. It was noted that cathode radiation could darken a photographic plate protected by a light proof folder.

Lenard observed that the rays scattered in all directions outside the aluminium window. He compared the absorption of cathode rays by

different solids and gases, and developed an aluminium ladder with one to nine layers of foil to analyse the penetration. He did not realise that after passing through the aluminium window they were mixed with another kind of ray. Years later Lenard became embroiled in a bitter controversy as to whether he, rather than Röntgen, should be honoured as the discoverer of X-rays.

On Friday, November 8, 1895, Röntgen had recently repeated Lenard's experiments with cathode rays from an aluminium window producing luminescent effects on fluorescing salts and darkening a photographic plate.

He noticed that a barium platinocyanide screen fluoresced despite the tube being shielded by black cardboard and despite the screen being at a much greater distance than observed in cathode ray experiments.

If this curious emanation could escape the light-proof cardboard box, could it penetrate other substances? Röntgen held a variety of objects between the tube and the screen. Most showed little reduction in the intensity of the glowing screen. Only lead and platinum obstructed the rays. He then observed the ghostly shadow of the bones and soft tissues of his own fingers. He replaced the fluorescent screen with a photographic plate and produced an image using the vacuum tube as a light source.

Röntgen realised this was a new form of light which was invisible to the eye and had never been observed or recorded.

For the next seven weeks Röntgen remained secluded in his laboratory, concentrating entirely on a large number of carefully planned experiments. "I have discovered something interesting — but I do not know whether or not my discoveries are correct".

"On a New Kind of Rays, a Preliminary Communication" was handed to the secretary of the Würzburg Physical-Medical Society on December 18, 1895. Röntgen requested publication prior to presentation at the next meeting.

To speed critical reading and evaluation of his work, Röntgen sent copies of the article and examples of prints of X-rays, to a number of well known physicists. To his wife he said, "Now there will be the Devil to pay".

Röntgen disliked the sensationalism of radiography, which he considered only a means of documenting his fluoroscopic observations and experiments. On January 23rd, 1896, at a public demonstration Röntgen addressed the Würzburg Physical-Medical Society. Although he lived another 27 years, this was the only formal lecture he gave on X-rays. At this meeting it was proposed that they be called "Röntgen's rays".

In March 1896 and May 1897, Röntgen issued further communications on the properties of X-rays. These were so detailed that Sylvanus P. Thompson complained "Röntgen had so thoroughly explored the new properties of the new rays by the time his discovery was announced, that there remained little for others to do beyond elaborating his work" (Eisenberg, 1992: 32).

The Discovery of Radium

Since fluorescence appeared to be necessary for the formation of X-rays, investigation then proceeded on the possibilities of naturally occurring radiation. Henri Becquerel, a professor of physics in Paris, experimented with uranium salts. As a result of his experiments he concluded that neither sunlight, fluorescence nor phosphorescence was necessary -- the rays were emitted spontaneously from all uranium salts and from uranium itself. Like X-rays, the radiation could not be reflected by mirrors nor refracted by prisms and could discharge an electroscope by ionising the surrounding air. Unlike X-rays, the new radiation was a specific property of the atom itself and actually represented the property of that matter.

Becquerel's paper "On Visible Radiations Emitted by Phosphorescent Bodies", presented to the French Academy of Sciences in 1896, interested Marie Sklodowska. She had joined her sister in 1891 at the Sorbonne to study mathematics and physics.

She met Pierre Curie in 1894. A physicist working at the Sorbonne, he was the son of a Paris physician. He had discovered piezoelectricity and with his brother Jacques constructed an electrometer which was later given their name. Marie and Pierre married in 1895

and 3 years later Marie selected Becquerel's "spontaneous radioactivity" for her doctoral research. After systematic purification of pitchblende, she announced the discovery of a new substance, a metal related to bismuth which she called Polonium.

The Curies subsequently recognised a second substance two million times more radioactive than uranium, which they called radium.

Marie Curie never adequately protected herself in all her years of contact, even though she insisted that safety precautions be taken by her colleagues and students. She eventually developed severe radiation burns on her hands and died on July 4th, 1934, of aplastic anaemia. At 67, she was three years older than the average life expectancy of women at that time.

In his Nobel lecture in 1904 Pierre Curie said, "One may also imagine that in criminal hands radium might become very dangerous, and here we may ask ourselves if humanity has anything to gain by learning the secrets of nature, if it is right enough to profit by them, or if its knowledge is not harmful."

Forty years later the secrets of nature had led to the development of nuclear fission and fusion, culminating in the development and detonation of the atom bomb.

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Röntgen Rays in Early Twentieth Century Medical Diagnosis and Therapy: Searchlight or Scalpel?

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Abstract: A comparison of the early medical use of Röntgen rays and the introduction of the stethoscope reveals some informative parallels and contrasts. Both technologies served a clinical need for visualisation, but the ability of X-rays to produce photographic and fluoroscopic images led to an overemphasis on the ways in which they were analogous to light rays and an underemphasis on the ways in which their biological effects differed from those of ordinary light. As a result of this attitude, many X-ray pioneers showed little concern for the possible dangers of this new technology, with adverse consequences for themselves and their patients. It is suggested that a different analogy for the medical use of X-rays would have encouraged a more cautious approach by these early pioneers.

This paper compares two technological innovations which were introduced into medical practice roughly a century apart, Röntgen's X-rays at the beginning of the twentieth century and Laennec's stethoscope at the beginning of the nineteenth century. While the early X-ray apparatus was a far more sophisticated device than the early stethoscope, both innovations made use of the principles of physics to provide important new clinical information, and both met a pre-existing medical need for "visualising" the internal organs of the living body. In some ways, one could say that X-rays completed the trend toward visualisation in medicine that the stethoscope began (Reiser, 1978).

To understand the relationship between these two technologies we must begin by considering the state of medical knowledge a century before Röntgen's discovery, at the outset of the nineteenth century.

In the years around 1800, medicine was abandoning its traditional understanding of diseases as complexes of symptoms, and adopting instead the concept that diseases were localised lesions of specific organs. Symptoms, which had previously been the principal defining characteristics of a disease, now became the external signs of internal lesions. To reach a correct diagnosis the physician had to form a mental picture of pathological changes in the body of the living patient which the autopsy would later reveal in the deceased patient's cadaver (Ackerknecht, 1967; Foucault, 1973).

For this reason, active diagnostic examination began to assume greater importance in clinical practice than had previously been the case. The objective was for the physician to be able to "see", at least in his imagination, into the living human body without damaging it in the process. In this context it is easy to understand how important the introduction of the stethoscope was when it was invented by the French physician Laennec in 1816 (Laennec, 1816). This instrument, the first piece of technology invented specifically for diagnostic use in clinical medicine (Reiser, 1978), allowed the physician to identify a wide range of pathological changes to internal organs, simply by listening to the sounds they produced.

The fact that Laennec named his instrument the stethoscope, or "chest-seer" rather than the stethophone, shows how important the visualisation of internal organs was to the medicine of his day. The physician who translated Laennec's treatise into English compared the use of the stethoscope to placing "a window in the breast" of the patient, "through which we can see the precise state of things within" (Forbes, 1821: xiv).

Although the concept of disease changed markedly over the next hundred years, especially with the introduction of the germ theory, the clinical need for visualisation was no less strong in Röntgen's day than it was in Laennec's. A number of endoscopic devices had been invented in the latter half of the nineteenth century, but these gave access only to limited areas of the body (Reiser, 1978). Röntgen's discovery overcame this limitation and was adopted for medical use around the world almost as quickly as information about it could be communicated. The medical use of X-ray technology seemed at last to provide a real "window" into the body, allowing the visual inspection of the patient's internal organs in a non-invasive way.

While it is appealing to contrast the real "window" produced by X-rays and the imaginary "window" resulting from the use of the stethoscope, we must not carry the idea of the X-ray "window" too far. It is true that X-rays produce visual data about the living body while the stethoscope produces only auditory data. But the way in which these visual data are produced by X-rays makes the "window" metaphor a rather misleading one.

Because the stethoscope was introduced as an auditory instrument, specifically applying the physical principles of acoustics (Laennec, 1816), it was immediately clear that any talk of using it to visualise the internal organs of the body was highly metaphorical. But Röntgen's X-rays were introduced into medicine in a visual context. Visible light had been conceptualised by nineteenth century physics as a form of electromagnetic radiation, and because Röntgen's new electrically produced rays left permanent traces on photographic plates they were soon being described as a new form of light (Grigg, 1965: 9).

Röntgen himself noted that "some kind of relation seems to exist between the new rays and light rays". But he concluded on the basis of

his experiments that X-rays "behave entirely differently from the infra-red, visible, and ultraviolet rays known at present" (Röntgen, 1895: 52, 51). The "window" into the body which X-rays opened up for clinical medicine was therefore just as metaphorical as Laennec's stethoscopic "window". The latter was based on a limited psychological analogy between seeing and imagining, while the former was based on a limited physical analogy between visible light and Röntgen rays.

For present purposes, the most important limitation of the analogy between visible light and Röntgen rays is that visible light typically provides us with visual data about objects (other than light sources) by being differentially reflected off those objects, showing brighter and duller surfaces, for example, or different colours. Röntgen rays, on the other hand, provide us with visual data about objects by differentially passing through those objects, showing the relative densities of the parts involved. The observer's best vantage point in the case of visible light is on the same side of the object as the light source. But in the case of Röntgen rays it is on the opposite side of the object, using a fluorescing screen, for example.

Thus the way in which visual data are produced by X-rays makes the "window" metaphor misleading because viewing an object through a window does not usually change it in any significant way. Viewing the internal state of the body by means of X-rays, however, depends on this radiation passing through the body and being more absorbed by some parts than by others. So while the analogy between X-rays and visible light may be useful for some purposes, for others — such as anticipating the effects of X-rays on living tissues — it is not.

When the effects of a technology are not well understood, as is usual in the case of technological innovation, we need to anticipate any hazards it might pose and estimate the risk involved in its use. Here we work from the best available information, but we interpret this information differently according to where we locate the burden of proof. Do we assume the technology is safe until proven dangerous, or dangerous until proven safe?

This was the question facing the early pioneers of Röntgen radiation, although they did not explicitly formulate it in this way. Judging from their behaviour, their answer was that X-rays were to be considered safe until proven dangerous. And my proposal is that part of the reason for this attitude was their overextension of the analogy between visible light and Röntgen rays — or "invisible light" (Grigg, 1965: 9, 170), as they were sometimes called.

It was initially assumed that looking into the body through the Röntgen ray "window" was as unlikely to harm it as looking at it with visible light would be. But by April 1896 accounts were being published of skin damage and hair loss in people exposed to X-rays. What is striking is the response to this information by people working with the new technology. Röntgen was "distressed" to believe that X-rays might cause such effects (Glasser, 1958: 90), and "many medical men were unwilling ... to admit that these results were due to the X rays themselves" (Eddy, 1946: 143; cf. Reiser, 1978: 67).

The burning and blistering of the skin after exposure to X-rays was immediately likened to sunburn (Glasser, 1932: 76, 78, 80), even though sunburn would not normally cause hair loss. I suggest that the light analogy inclined people toward this interpretation. It also offered a way to exonerate X-rays from the accusation that they were dangerous, since many argued that X-rays, like visible light, were harmless in themselves and that associated ultraviolet radiation was the cause of skin damage.

Other causes were also proposed, although experiments reported by Elihu Thomson in 1896 supported the conclusion that X-rays themselves and not associated phenomena caused tissue damage. Nevertheless "even as late as 1903 there were still writers who contended that the injurious effects were due to ozone, chemical effects or to electro-static discharges" (Christie, 1928: 296). And Thomson himself later complained that "in spite of the deliberation I used [in exposing his hand to X-rays], I have seen this burn of mine erroneously described as the result of an *accident*" (Thomson, 1932: 386).

So even though by August 1896 "several reports had appeared of extensive damage to hands and face and evidences of radiation sickness were described" (Eddy, 1946: 143), and although deep tissue damage had been

observed by 1897 (Christie, 1928: 295), many of those working with X-rays continued to treat the effects of exposure as superficial and transitory, just as the effects of sunburn were thought to be at that time.

Since most of the visible damage to exposed skin appeared to heal fairly quickly, it was common for X-ray personnel to avoid further exposure when symptoms appeared, but then to return to work when it seemed that healing had taken place. "This fact," as Eddy writes, "coupled with the ignorance of the long-term effects which gave no early visible evidence, led to the unhappy experiences of many pioneers" (Eddy, 1946: 143) in the early twentieth century. And the same may no doubt be said of many patients on whom X-rays were used for diagnostic or therapeutic purposes.

A more balanced assessment of the biological effects of X-rays came from Joseph Lister in September 1896. After commenting on the diagnostic value of X-rays, Lister added: "It is found that if the skin is long exposed to their action it becomes very much irritated, affected with a sort of aggravated sunburning. This suggests the idea that the transmission of the rays through the human body may not be altogether a matter of indifference to internal organs, but may by long continued action produce, according to the condition of the part concerned, injurious irritation or salutary stimulation" (Lister, 1909: 491).

In these remarks Lister recognised that the visible similarity between the symptoms of sunburn and those of X-ray burns was a matter of superficial resemblance only. The important difference between ultraviolet light and Röntgen rays was "the transmission of the rays through the human body". In addition, Lister recognised that the internal effects of these rays could be either harmful or beneficial, according to the circumstances involved. In this way he signalled both the therapeutic potential of X-rays and the caution needed in applying them for either diagnostic or therapeutic purposes.

Lister was a distinguished clinician, but he was not directly involved in the use of X-rays. This situation seemed to allow him a greater degree of objectivity in assessing the potential medical consequences of X-rays than many of the X-ray pioneers exhibited. For those most closely involved in early medical X-ray work, the suggestion that X-rays were in any way dangerous tended to produce resentment rather than caution (Grigg, 1965: 39). Their enthusiasm for the new technology caused them to take the analogy with light too literally and to expose both themselves and countless patients to harmful levels of radiation.

At the outset of this discussion we noted how medical use of the stethoscope was compared to viewing the body's interior through a window. One physician offered a quite different metaphor of the process, however, when he wrote: "We anatomise ... while the patient is yet alive" (Latham, 1835-36). If the medical use of Röntgen rays had initially been compared to opening the living body with a scalpel rather than projecting light into it through a window, I suspect that more of the early pioneers of medical X-rays would have shared the perspective of Lister, who was, after all, a surgeon. This surgical analogy would probably not have dampened their enthusiasm for the valuable potential of this new technology, but it would have highlighted the need for them to balance their enthusiasm with prudence.

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The Role of Röntgen Rays in Contemporary Medical Imaging

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Abstract: In a matter of weeks following Röntgen's provisional communication of 28 December, 1895, X-rays were being used for clinical diagnosis. Starting from crude, and often dangerous, technology, progress to the production of images of excellent quality and radiation safety was inexorable. For a hundred years, X-rays have been the mainstay of medical imaging, providing invaluable information for the diagnosis and management of disease. The ability to visualise pathology within the intact body also led to advances in medicine and surgery. The introduction of Computerised Tomography, which

utilises X-rays in a different manner, has, in recent years, revolutionised the practice of medicine. Recent decades have seen the introduction of imaging modalities which do not utilise X-rays — notably Ultrasound and Magnetic Resonance Imaging. Whilst these have replaced X-ray examinations to some extent, the latter remain the preponderant form of imaging, and Röntgen's X-rays are alive and well in medicine a century after this great discovery.

The discovery of the physical properties of X-rays produced a major advance in medical science. For the first time, organic pathology could be visualised within the intact body. In a matter of weeks, from Röntgen's provisional communication of 28 December, 1895, X-ray examinations of clinical value were being obtained both in Europe and America — of metallic foreign bodies, fractures and other bone abnormalities. In England, Sidney Donville Rowland began a radiology practice as early as March, 1896. In the same year, Thomas Edison developed the use of a fluorescent screen as an alternative to recording the image on a photographic plate. This method refined over the years to reduce dosage and improve contrast and spatial discrimination and remains an active service for visualisation in real-time.

Apart from the noxious effects of overexposure to X-rays, which cost the lives of many of the early pioneers, it was recognised early in the history of this new branch of medical science that there were limitations to the diagnostic information that diagnostic X-rays could provide. Essentially, conventional diagnostic X-rays allow the discrimination of only six basic densities: gas, fat, soft tissue and fluid, bone, calcium and heavy metals. A normal, or pathological structure, has to be "outlined" by tissue of different density in order to be imaged.

For instance, the multiple organs within the abdomen are largely of soft-tissue density and their outlines hard or impossible to detect on conventional X-rays. A tumour within the liver substance cannot be detected since both tumour and normal liver are of the same density. Only the gas-filled stomach and colon are clearly visualised within the soft-tissue background.

The problem was partially overcome by introducing substances of different density into body "cavities" by various means. Barium could be used to outline the digestive tract, air introduced into the brain ventricular system by lumbar puncture, or iodine compounds utilised to demonstrate the urinary tract as they were excreted by the kidneys.

The power of the X-ray beam required to penetrate and depict bony structures such as the skull or spine, was such that the important structures of the brain and spinal cord could not be seen at all, although some information could be obtained by outlining the subarachnoid space or appropriate arteries with contrast agents.

A major advance in the use of Röntgen rays occurred with the development of Computerised Tomography (CT) (Hounsfield, 1973). Although similar in principle to conventional radiography, in that the produced image is a grey-scale representation of the degree to which body components alternate the X-ray beam, CT employs multiple collimated X-ray exposures, sophisticated electronic detectors, and computer analysis and refinement, to produce a cross-sectional slice of body tissue. Movement of the X-ray source around the body allows multiple readings of small volumes of tissue within the slice to provide a cross-sectional image which avoids superimposition of structures and accurately indicates their density so that soft-tissue structures can be differentiated both in outline and density. With this method it was possible, for the first time, to depict the structures of the brain and spinal cord, and to detect soft-tissue abnormalities within soft-tissue structures, e.g., tumours, abscesses and haemorrhages in the brain and in abdominal organs.

Intravenous injection of an iodine containing contrast medium is frequently used during CT examinations to provide further contrast differentiation between normal and abnormal tissues and to visualise vascular structures.

Advances in CT technology now allow for 3D reconstruction, fine-section examination of complex and relatively minute structures and image manipulation. CT can thus be used, not only for diagnosis, but also to plan surgical, radiotherapeutic or other forms of therapy, accurately place needles percutaneously for biopsy and provide excellent visualisation for interventional procedures, such as drainage of abscesses.

There are available other important means of imaging that do not use Röntgen rays. Radioisotopes can be introduced into the body and the emission of gamma rays detected by an external gamma camera. Since the substances used have radioactivity, this method requires the same attention to dosage and safety as is required for Röntgen rays. Further, the images obtained do not provide the contrast range and anatomical detail of Röntgenograms. They do, however, provide very useful information regarding function and an area of functional abnormality, e.g., bone infection or impaired renal function, can be detected in the absence of detectable changes on radiographs. Radioisotope scanning of the lungs similarly may detect the occurrence of pulmonary embolism in the presence of a normal chest X-ray.

Ultrasound was developed as a modality for medical imaging in the early 1960s. In this system, high-frequency sound produced from a transducer of piezoelectrical material is transmitted as a longitudinal wave into the tissues. The sound wave is reflected back to the transducer from tissue boundaries and the transducer can detect these during a "listening" phase. The returned signal is converted into an electrical signal, with an electronic display which displays the returned echoes as variable levels of brightness on the screen. The information can also be manipulated by a computer. The operator, by sweeping the transducer over the body part, can build up a series of images which demonstrate the anatomy in various phases of section, and sees the image display in real-time.

A major advantage of diagnostic ultrasound over Röntgenography is the absence of ionising radiation. This has proved of particular advantage in the imaging of the foetus in utero because, not only is the danger of radiation eliminated, but also the soft tissue structures of the foetus, placenta and uterus are clearly visualised. Ultrasound has revolutionised the practice of obstetrics as CT revolutionised the practice of neurology.

Apart from obstetrics, diagnostic ultrasound has an important role in the imaging of the liver and biliary system, the kidneys, and other abdominal organs, and in the heart. Functional assessments can be made such as detection of the foetal heart beat and assessment of the function of the heart muscle and valves in the adult patient. The Doppler phenomenon of sound is utilised to determine flow in arteries and veins, and many invasive radiological procedures that were previously necessary can be avoided.

The major disadvantage of ultrasound is the difficulty of imaging where there is bone or gas-filled structures which deflect and distort the image. It has, however, been used to good effect to image the structures of joints, such as the shoulder and hip.

The latest addition to the armamentarium of the diagnostic radiologist is Magnetic Resonance Imaging (MRI). The physics of this technique is formidable but, in essence, the response of hydrogen protons to a varying magnetic field is detected electronically and their situation in the body located by gradient magnetic fields in three planes. An image can thus be formed.

MRI provides images of exquisite anatomical detail. It is of particular value in the brain and spinal cord, but also can provide detailed anatomical images of joints, muscles, abdomen and heart. Special techniques and image manipulation allow functional studies such as assessment of cardiac function and the flow of cerebro-spinal fluid.

The "magical" rays which Röntgen discussed have made an enormous contribution to medical science in the twentieth century. Without them, many other medical and surgical advances would not have been possible.

As discussed above, there are now several other forms of imaging available. How well has Röntgenography survived after 100 years?

Indeed, Röntgenography is alive, well and flourishing. It remains the predominant means of imaging the chest, since the air-filled lungs

give excellent contrast delineation from pathological processes; it remains the best method for examining the skeletal structures, particularly for suspected fractures and joint disorders; the plain film of the abdomen remains the prime imaging tool for suspected bowel obstruction and kidney stones.

The new modalities have replaced some previously common radiographic procedures, either because more useful information is obtained or because interventional procedures are avoided. The pneumoencephalogram, in which air injected into the spinal subarachnoid space outlines the brain ventricular system, has been completely replaced by CT and MRI. This was an unpleasant procedure for the patient, gave limited information, and had potential complications. The new modalities provide much better information without the previous discomfort and dangers. Similarly, the injection of a contrast medium into the bronchial tree, bronchography, has been replaced by CT — again, discomfort and complications are reduced and more useful information is obtained.

Many radiographic procedures remain in use but have been partially replaced by other modalities: ultrasound may be used to visualise the kidneys rather than an intravenous pyelogram which involves injection of an iodine-containing compound and multiple radiographic investigations. The barium meal for stomach problems has been significantly replaced by endoscopy which allows direct inspection of the gastric mucosa; CT, rather than a skull X-ray, is the procedure of choice for a serious head injury; MRI is the definitive examination for suspected multiple sclerosis.

Angiography, although replaced in some areas by other modalities, remains an important radiological investigation. Catheters, introduced via a peripheral artery, can be introduced into the aorta or its branches and the flow of an injected contrast medium visualised in real-time or on multiple radiographic images. This technique is currently employed, particularly for atheroma and other arterial disorders which reduce blood flow to the limbs, brain or heart.

The ability to introduce catheters into the arterial system has led in recent years to the exciting, new sub-specialty of interventional radiology. Sites of bleeding, congenital vascular abnormalities and some tumours can be treated by obliterating the feeding arteries with suitable injected material. Selected vascular lesions occurring in the brain may also be treated in this manner.

Further important angiographic interventional techniques in frequent use are the dilatation of narrowed arteries by balloon catheters and the insertion of metallic filters into the inferior vena cava in the management of pulmonary embolism from venous thrombosis in the legs. The techniques of vascular intervention have been adapted for use outside the vascular system, and have allowed for the replacement of surgical techniques for some pathological procedures. For instance, catheters can be introduced percutaneously to drain obstructed kidneys, obstructed bile ducts, abscesses or other fluid collections; narrowed areas in the urinary tract or biliary tract may be treated by percutaneous passage of a stent that can be left in situ to provide drainage through the narrowed area or dilated with balloon catheters.

The field of interventional radiology is a fertile one for the inventive and skilful radiologist, and one where Röntgen rays provide significant contribution to the treatment of disease as well as its diagnosis.

After 100 years, and the introduction of competing technologies, the rays discovered by Röntgen still provide the majority of imaging investigations and provide a major contribution to both diagnosis and treatment of disease.

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Roentgen Rays, An Indispensable Tool In Contemporary Engineering And Science

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Abstract: The use of radiographic methods in non-medical science and industry is widespread and long established. Growth in its application can be shown to follow the technological development of radiography equipment. The scope of applications vary from an atomic level in the examination of crystals to the evaluation of structures as large as buildings. Many applications are related to public health and safety, hence radiography makes a significant contribution to society. However most people in the community are unaware that their lives are improved by its use.

Introduction

Wilhelm Conrad Röntgen's discovery of X-rays in 1895 should not be considered in isolation, for this was a period of several significant scientific achievements in the understanding of the physical world. The notoriety of the discovery may be traced to its ability to produce dramatic images of what had hitherto been hidden, whether this be anatomical structure or an inanimate object. The presentation of some of these images in the newspapers and other print media stimulated an interest in the work at all levels of the community and the sciences. Along with medicine, engineering and science have made use of Röntgen's X-rays from a very early stage. The method is used in science as a research tool and in industries such as automotive, chemical, manufacturing, aerospace and mining as an aid in both production and maintenance. Its acceptance and efficacy in many applications has placed it in a unique position as an investigative method of immense value; but for the general public, the use of non-medical X-ray technologies goes mostly unseen.

Present Applications

It is not possible here to detail fully the uses to which Röntgen's discovery has been put. What follows is a broad cross section of applications which should leave the reader with an impression of the diversity of its use and the value that it adds to our contemporary way of life.

X-ray Microscopy

The use of X-rays for micro-investigation is shared by scientists in biology, chemistry, physics, geology, metallurgy, and other disciplines. The main advantage of extending microscopy to the X-ray wavelength is the increased penetration and higher resolving power which permits examination of mediums that are opaque to light.

Microradiography

Early radiographic examination of very small objects by Heycock and Neville around 1887 was made by enlarging the film. Modern methods utilise X-ray sources as small as 8-15 microns to project images of very small objects. Computer programs for image enhancement and manipulation are essential for some applications.

X-ray Diffraction Techniques

X-ray diffraction techniques use radiation of a single wavelength. The equipment consists of an X-ray generator, a goniometer (a device for measuring angles in a crystal or prism), X-ray detector, a rate meter and scaler. In 1912 Max von Laue found that some X-rays diffract when passed through very thin sections of crystals. The parallel planes of the crystal are spaced at the same dimensional order as the wavelength of applied X-rays and they diffract the beam as it passes through the crystal. The diffraction of

the beam may be measured. This can be related to the crystalline spacing and hence the structure of the material.

Security

The security scanning of baggage prior to its being loaded aboard an aircraft is accepted as standard procedure for enhancing safety. Although the technology was well established, its worldwide application was brought about by a proliferation of terrorist activities against some commercial airlines in the 1970s. Today's regular passenger would probably be disconcerted if this examination was not performed. Modern inspection units use power levels of between 90 and 160 kV, electronic zoom, image enhancement, pseudo colour and silicon diode array sensors which effectively image the item with only a very small amount of radiation. As a guide to the flexibility of these devices, they have the ability to examine dense and light materials in a single image. Skilled operators can also distinguish between plastic explosives and harmless materials. Baggage which is loaded in the under floor area is also examined in this way.

Similar equipment is becoming commonplace anywhere that security needs to be enhanced. Courts, government buildings, prisons, consulates, foreign offices, and even some museums and art galleries are using this technology.

Forensic Science

Special radiographic techniques may be applied to very thin or low atomic number materials. Such is the case in some forensic examinations. X-rays generated at about 5-25 kV are used for this purpose. In situations where fingerprints are difficult to "lift" from a surface or not easily photographed, conventional X-ray may be used after the fingerprint is treated with a type of lead powder. It is even possible to image fingerprints which are deposited on skin tissue or other parts of the body. Post mortem examinations usually use low power industrial X-ray units because radiation exposure of the subject is not a safety consideration. These examination results may be included into court's evidence in circumstances where identification of a subject is made by comparing previous radiographic records with images made during post mortem examination. Radiographic techniques can also suggest bone age where the subject is less than 25 years old. The use of contrast media can be introduced into damaged tissue to show the extent of wounds.

Other forensic uses include the examination of documents, bank notes and securities, and even the evaluation of gunpowder patterns of bullet holes.

Art Works and Antiquities

Those involved with the validation and restoration of art works have made use of X-radiography. In the past several years for example, Australian Defence Industries (ADI) have used radiography to examine various bronze statues around the Sydney city area to assess their condition before the cost of restoration work could be estimated. Such examinations are routine for museums involved in the care and investigation of art works and antiquities.

Industrial Radiography

Many products and processes have radiography as an essential part of manufacture and maintenance. The routine examination of casting, forgings, assemblies and other fabrications ensure quality and conformance with customer specifications. The automotive industry for example examines such things as vehicle tyres for correct placement of reinforcing wires, brake assemblies for proper assembly and aluminium alloy road wheels for internal defects such as voids and inclusions which could adversely affect the service life of the part. These applications are examples of how the manufacturers of auto parts and vehicles enhance the safety of road vehicles by minimising the occurrence of mechanical failure.

Ships, pipelines, storage vessels and petrochemical plant contain a high proportion of welded fabrication. The examination of the welds at the time of construction and during maintenance is standard practice using radiography as well as other non-destructive means. The consequences of a defect passing undetected will of course vary depending on the item examined. It may only be a nuisance or could pose a significant hazard to the public and property. As an example, consider pressurised and unpressurised storage vessels which are subject to inspection in accordance with strict

codes. It is not difficult to envisage the problems which could be caused should the contents be uncontrollably released as a result of a structural failure.

Public structures such as buildings and bridges may also be radiographically examined to ensure their integrity. One interesting example is the Statue of Liberty in New York harbour. As part of the refurbishment of the statue for its centenary in 1986, its steel framework which supports the outer copper cladding was radiographed to establish the extent of corrosion which would necessitate repairs.

Aerospace and aviation has long been recognised as an industry where components are designed to marginal limits yet must have a very low probability of failure or malfunction. Evaluating the condition of aircraft and spacecraft requires many specialised inspection techniques. Radiography is one such technique which is very important to this industry and in some circumstances cannot be substituted by alternative methods. At manufacture many of the parts and assemblies are radiographed for the same reasons as the automotive examples. However in addition to this, at preplanned maintenance intervals parts of the structure which may suffer damage, usually by fatigue, are examined by radiography. Fuselage and wing panels are subjected to cyclic loading which, when occurring at an area of stress concentration, can develop cracks. These may be detected by radiography. Engine components are radiographed for correct assembly, internal defects and at areas where weld repairs have been made. In some circumstances the condition of a part may be monitored by comparing the radiographic images from past inspections to those of the present. This permits the part to remain in service for its maximum safe life.

The food industry like others would wish to avoid the expense of a product recall or product liability claims where contamination is found in their products. To address this issue, products ranging from meat pies, processed cheese and baby food to confectionery and potato crisps are subjected to radiographic examination for contamination such as metal filings and broken glass. Provided that the contaminant has a radiographic opacity which is different to that of the product, it will probably be detectable by X-ray methods. A similar application is used to detect high density carbide chips from machine tools which can contaminate recycled titanium. If left undetected these chips can find their way into the melted metal and form inclusions from which larger defects may develop.

As a final example of the practical uses of X-rays, consider their application to the detection of the internal degradation of timber power poles. The pole's structural integrity may be significantly reduced with no external indications of the decay within. Several systems have been developed using X-ray tomography to examine the base of timber power poles. Internal cavities caused by rot and natural ageing can be clearly identified, which provides the power authority with timely information for the management of a replacement program for these timber poles maximising the pole's useful life.

Conclusion

What has been attributed to Wilhelm Röntgen was a unique and novel discovery. It captured the imagination of scientists, and the community at large. He received awards, recognition and tributes from foreign governments, heads of state, universities and institutions. Even royalty and politicians sought him out to demonstrate and explain what he had found. Busts and statues were commissioned. Röntgen was a true celebrity of his time, and one can only wonder what a person of science would need to accomplish today to achieve the same degree of recognition.

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Goethe's Scientific Ideas and the Advancement of Experimental Science since his Death in 1832.

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Abstract: This paper looks at Goethe's scientific theories and the aspects that caused them to have so little influence on experimental science in the nineteenth century. Essentially these were that he believed in nature as a unity that should not be interfered with but observed; that hypotheses would lead to finding only what one was looking for; and that the mathematical model is an inadequate way of explaining the world — ideas that went against the basic tenets of empirical science, so that despite his own discoveries, he was respected only as a poet. The twentieth century has come to value his holistic approach to nature and his historical approach to notions of truth.

A topic containing words like "Goethe and..." suggests some kind of influence, in this case an influence the great poet's scientific ideas might have had on experimental science after his death. If we can establish such an influence, well and good, but if not, what then? Let me say at the outset that most of those who have found an influence have approached the question from the literary side, while those who come from science have generally not found an influence. I also freely admit that I come from a background in literature. Even so, I should like to turn the question around somewhat and — assuming the scientists know their business better — ask not only how can it be that he had no real influence but, perhaps more significantly, how could experimental science in Germany have proceeded in spite of him?

To put this into a clearer perspective: the intellectual climate in nineteenth century Germany was completely dominated by a man of astonishing energy and productivity, the intellectual giant that was Goethe, sometimes called the last Renaissance man who knew everything there was to know in his time. Not only was he acknowledged as the greatest German writer, but he had written on almost every subject. Composers set his poems to music, his works were studied and actually read at schools and universities, he was generally revered as the great national sage. There was no getting past him: Schopenhauer had wanted to be a writer but became a philosopher instead because he realised he could not compete, and even in Sydney, when Ludwig Leichhardt arrived in 1842, he befriended a man who had translated some of Goethe's poems! (Roderick, 1988: 170) Goethe had published many of his ideas and so had to be part of the debate, and further, one of his central ideas was the notion that the individual had to be seen as a whole, that is, you could not like Goethe's *Faust* and reject his science. In view of all this, and given that Goethe had rejected experimental science, it is amazing that Helmholtz, Hertz, Liebig, Koch and Röntgen happened at all.

To examine this problem in the sociology of science, I should like to proceed by looking at Goethe's main scientific ideas and how he arrived at them, then at their influence in the nineteenth century, how they have fared in the twentieth, and to conclude with some observations on the issue as a whole.

Goethe's father wanted him to be a lawyer, but the young rebel attended lectures in all manner of areas including medicine, which was where one did science in those days. It was not until after his appointment to the court in Weimar at the age of twenty-six in 1775, however, that he began to take a serious interest in scientific matters — he needed botany to cope with managing the forests, geology because he was in charge of the mines and so on. From this purely practical motivation, his interest quickly generalised to embrace what we would call pure science, that is, the theoretical underpinnings, and he did so with characteristic energy and intensity, especially between 1782 and 1810.

His fundamental idea is an ultimately religious belief that nature is an emanation of the divinity and therefore a unity, a mix of Plato and Spinoza (Nisbet, 1972: 6-22). This wholeness of Nature manifests itself as a polarity, such as light and dark, positive and negative electric poles, and what he calls "Steigerung" (intensification). From this it follows that understanding of the physical world — "der Gottheit lebendiges Kleid", as he puts it in *Faust* — can result only from observation and not interference. By observation he means collecting data and then trying to see what the data mean on the level of an Idea (Goethe, 1823). He did not approve of doing violence to Nature, "torturing" it to produce certain phenomena, as Newton had done in forcing light through a small hole and then through a prism; because then the results would be based on an unnatural situation and not nature. He was opposed to hypotheses, as these would lead the scientist to see what he is looking for and not what is there. He believed that the results of experiments ought to be in a form comprehensible to the intelligent lay person. He was unfortunately bad at mathematics and in particular he despised applied mathematics; this meant that he rejected the descriptions of the world in terms of mathematical models that were becoming increasingly necessary and thus common in just the period when he was developing his most controversial theories, those in physical optics. He preferred what he called symbols, and refused to accept that what mathematics provides is essentially also a symbolic description of phenomena. In many ways, he was the epitome of a reasonable, if not a rationalist eighteenth century man.

The principal areas in which he was active, and which fill thirteen volumes of the Weimar edition of his works, were anatomy, botany, zoology, geology, mineralogy, physiological and physical optics, meteorology and the history and theory of science. As his work has been well documented (e.g. Wells, 1978), there is no need to recapitulate it here; suffice to summarise by saying that he is credited with the discovery of the intermaxillary bone in humans, and with major contributions both to physiological optics, in his study of subjective reactions to colours, and to what became known as evolution, in his work on "metamorphosis" (Weizsäcker, 1955: 537) — not bad for a man who actually earned his living being a sort of super-bureaucrat running a number of ministries including war, finance, justice, roads, and education (admittedly in a relatively small though independent duchy).

The significance of the intermaxillary bone is that its absence in humans had been taken as evidence that man was not related to the apes (Weizsäcker, 1955: 545), though Goethe did not pursue the implications. His work on the metamorphosis of plants involved a great deal of accurate observation and classification. Clearly his idea was not evolution in the Darwinian sense (Wells, 1978: 45), a concept with which most people at that time had great difficulty. Rather, he was searching for the "Urpflanze" (archetypal plant) of which all others were adaptations, which we might think of as a kind of Platonic idea with real existence. He reported accurately and interpreted phenomena in physiological optics, particularly in relation to negative after images; some of these have still not been better explained. These were his successes. It is obvious that his discoveries could be, and indeed were, made using the approaches he advocated.

Goethe's other work did not meet with the same acceptance. His idea that the skull of mammals is an extension of the vertebræ would require such a vague definition of vertebræ as to be useless, as Helmholtz pointed out (Helmholtz, 1876). In his studies in geology and mineralogy he made perfectly reasonable assumptions on the basis of the evidence available, for instance he correctly attributed the North German erratics to glacial transport, i.e. he posited an ice age, but generally there was simply not enough evidence available at the time. Indeed, the main problem was that people were still thinking of the age of the earth in terms of thousands of years. This applies also to his work on zoology and botany (Wells, 1978: 70). His meteorological studies involved assembling typical barometric readings and trying to come to some general conclusions about them; they were ignored at the time and have not been revived since.

It was his colour theory, however, that most obsessed Goethe (Reinhardt, 1986). Despite acceptance of his ideas in physiological optics, it was his dispute with Newton on the physical side of optics that occupied him most, causing him to write his longest work. This argument has been discussed in great detail (Wells, 1978, Groth, 1972, Burwick, 1986, Fink, 1972, Gögelein, 1972 and others) and there is no need to rehearse it here. What is important in it is the vituperation and rationalisation Goethe invested in it, for it shows that he could not bear to be wrong and that he built a very elaborate system around it in order to vindicate his own organic, anti-mechanistic approach to nature. Indeed his writing of history and theory of science is all designed to show that Newton ushered in an unproductive age not of science but of superstition, while the new fruitful age at the end of the eighteenth century culminates in Goethe himself (Goethe, 1810; Groth, 1972).

Taken as a whole, Goethe's lasting contribution to science is not enormous, compared to, say, Röntgen. In many cases, he simply did not have access to the data that would have allowed him to arrive at what we now consider the right conclusions. Above all, however, he adheres to his system of nature even at the cost of his avowed methodology. For instance, despite what he said about hypotheses, he almost certainly started with the notion that an *Urpflanze* existed and could in fact be found, possibly in Sicily (Goethe, 1787). He also used microscopes, telescopes and other apparatus to conduct experiments.

Goethe was probably unfortunate in living at the beginning of an age in which pure observation was no longer sufficient and he did not understand the branch of science that would now be necessary — mathematics. Nor was his holistic system appropriate in a time of vastly more complex and abstract kinds of

science. And so it was that while everyone read and admired his literary works, both his successful and his unsuccessful science came to be disregarded, and men like Helmholtz could quietly get on with analysing the world.

What about Röntgen? Surely forcing negative charges through very low pressure gases is far removed from everyday, natural life. Would Goethe have thought he was putting nature on the rack, discovering yet more of those wretched rays that are said to be behind colour? Or would he have thought here was a man playing serendipitously with a new piece of equipment in order to get to the bottom of nature's secrets and, by closely observing the results, come up with an explanation that would lead to one of the most helpful inventions of recent times? Even if he thought, as many people did at the time, that here was an ultimate invasion of privacy, another part of him, the scientist, would surely have been impressed by the capacity of the new machine to help us visualise. Goethe referred to himself as an "Augenmensch", as a man of the eye, so he could not help but be overwhelmed by the capacity of X-rays not just to *see*, but to enable us to see through the mortal coils to the structure underneath. In the *Magic Mountain*, Thomas Mann has his young hero see his cousin in an X-ray machine, and this makes him think of death and of his cousin as a skeleton. Not so, I think, the scientist Goethe, who was accustomed to handling skeletons — he would have seen the underlying structure, the basis that holds the body together, the skeleton as a living and functioning mechanism, a vision of the "original body". And because it was true, for Goethe it would have been beautiful.

While the second half of the nineteenth century was dominated by a very positivist approach to science, the end of it started revealing mysteries no longer explicable by the classic Newtonian model. This also pointed to the relative nature of scientific truth more than previous changes had. In our own day, there is a much greater interest in seeing the world from a holistic approach, and environmentalism could look to Goethe as its forerunner. As Sir John Maddox said recently, we should think of ourselves as being at the *beginning* of science, not as its greatest achievement. Thus the issue may be not whether Goethe was wrong, or science was right, it may be whether Goethe's theory that science moves in ever expanding spirals is perhaps the best way of looking at the advancement of knowledge.

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NEWER APPROACHES IN INTEGRATED TREATMENTS FOR LOCALLY ADVANCED CANCERS

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Over the ages medical practitioners have searched for and applied a large number of medicinal agents (including herbs and toxins), physical and chemical agents, dietary changes, spiritual activities and a variety of potions and local applications in attempts to find a cancer cure. However a somewhat crude form of operative surgery was the only effective anti-cancer treatment available until approximately 150 years ago.

The situation changed after the discovery of general anaesthesia in 1842 when painless surgery became possible. An era of severe surgical cross-infections followed the new upsurge of pain free operative surgery. This was changed by the work of such greats as Lister, Pasteur, Semmelweis and Koch who discovered the association between micro-organisms and wound infection. They introduced aseptic techniques for surgical operation. This combination of surgery under anaesthesia with aseptic technique was the basis upon which the modern era of great advances in operative surgery was founded allowing treatment of many diseases including cancer.

The second effective modality in cancer treatment, radiotherapy, was introduced less than 100 years ago. This followed the work of the Curies in discovering Xrays at the turn of the century.

Thus for most of this century localised cancers have been treated either by surgeons or by radiotherapists. Sometimes operative surgery and radiotherapy have been used in combination in integrated treatments particularly for such tumours as small localised breast cancers. After surgical removal of the obvious cancer, follow up radiotherapy is often used in an attempt to cure without total removal of the breast.

The first effective medical anti-cancer agents were discovered about 50 years ago. First certain hormones were found to affect growth of some tumours followed by discovery of the first effective cytotoxic anti-cancer drugs. Thus a third effective anti-cancer treatment modality was developed.

Early in the use of the new anti-cancer agents an accidental discovery led to a technique of more effective use of these agents in treating some cancers. It was observed following accidental injection of one of the agents into an artery rather than a vein there was considerable reaction in the tissue supplied with blood by the artery. This led to a belief that drugs given into an artery supplying a tumour region should have a greater anti-cancer effect in that region than drugs distributed equally throughout the circulation by the usual systemic or intravenous route.

As surgeons treated most patients with cancer and surgeons had the facility of exposing and injecting arteries with drugs, surgeons were amongst the first clinicians to use anti-cancer drugs to treat their most difficult cancer problems. Unfortunately initial experience in doing this was disappointing. When used by medical colleagues the drugs appeared to be active against a number of tumours which were widespread throughout the body but they appeared to have little beneficial action on locally advanced tumours treated by surgeons whether or not intra-arterial infusion of the agents was used. Surgeons therefore lost interest in the use of anti-cancer agents, particularly in treating locally advanced cancers, even when given by intra-arterial delivery. The use of these new agents was left largely to haematologists and other physicians who treated more responsive widespread malignant disease.

Some years later it was appreciated that the predominant reason the early experience of surgeons was so disappointing was that the drugs had been used largely to treat patients who had tumours which had recurred after initial attempts

at surgical resection and/or treatment by radiotherapy had failed. These recurrent tumours were in tissues to which the blood supply had been compromised by previous operative surgery and/or by radiotherapy. Thus the agents used being carried in the locally reduced blood stream could not reach the tumour tissue in effective concentrations. However by this time surgeons in general had lost interest in the use of the drugs and their application was reserved mainly for palliative treatment of widespread cancer and later treatment of a small group of uncommon cancers which were unusually sensitive to certain anti-cancer agents.

Thus for the past 50 years there have been 3 main methods of anti-cancer treatment. In general localised cancers have been treated by surgical removal wherever possible or by radiotherapy. More widespread cancers have been treated by medical oncologists by systemic injection or infusion (ie. given intra-venously equally to all body tissues) either to get palliation of symptoms or as "adjuvant" treatment. Adjuvant treatment is treatment given after the main cancer has been effectively removed by surgery or radiotherapy but there is a significant risk that small numbers of malignant cells may have already spread to other parts of the body. These scattered cancer cells are likely to cause tumour recurrence (metastases) in a distant tissue. "Adjuvant" treatment is usually given by a medical oncologist after a surgeon or radiotherapist has dealt with the original primary cancer. Breast cancers and bone sarcomas are the most common malignant tumours to be treated by adjuvant chemotherapy after operative surgery because with these tumours there is a considerable risk that malignant cells have already broken away from the original (primary) tumour and may be starting to develop new cancer colonies (secondaries or metastases) in other tissues. Breast cancer cells and bone sarcoma cells are sensitive to anti-cancer drugs so that adjuvant chemotherapy can be very effective in destroying small colonies of cancer cells before they develop into significant metastatic cancers.

A fourth treatment modality, immunology, has been the subject of intensive research over the past two decades. There has been great hope that a new and more effective immunological anti-cancer treatment modality would be found. In spite of studies in immunology giving much increased knowledge about tumours, until recently most of the expectations and great hopes that have arisen from time to time have not resulted in any significant improvement in treatment. However, quite recently immunological studies have been more encouraging. There are now prospects of an effective immunological anti-cancer agent becoming available. This new discovery is called tumour necrosis factor (TNF). This product of immunology research appears to be too toxic for effective clinical use on its own and too toxic to give systemically to the whole body tissues. However when used in small doses with other anti-cancer cytotoxic agents better results have be achieved in treating some cancers than from using cytotoxic agents alone.

In spite of the original disappointing results of most surgeons who first used anti-cancer drugs by intra-arterial infusion some surgeons continued to believe that there should be a role for use of anti-cancer agents given intra-arterially to treat aggressive or advanced cancer in a localised region. The benefit of this technique is now being widely appreciated.

It became clear that provided anti-cancer drugs were infused into the tumour blood supply whilst the blood supply was intact and had not been damaged by previous operation or radiation the regional tumour response could be considerable. It was therefore apparent that to achieve the most effective response of locally advanced cancers with chemotherapy the anti-cancer agents should be used before either operative surgery or radiotherapy had damaged the tumour blood supply. Thus intra-arterial chemotherapy is best given before surgery or radiotherapy rather than after. When anti-cancer drugs are given as the first treatment either systemically or preferably into the arteries of supply by intra-arterial infusion or perfusion many large and aggressive tumours can be reduced in size and aggressive qualities. Such tumour reduction can make the tumours more curable by following radiotherapy and/or surgical resection. In early experience when the drugs were used last the results were poor but when the drugs are used first in a combined treatment program, the results of treatment of large and aggressive tumours are significantly better. Such treatment was subsequently referred to as "neo-adjuvant" chemotherapy although a

more appropriate description of the use of chemotherapy first is *"induction chemotherapy"*. By induction chemotherapy is meant using chemotherapy to induce changes to achieve reduction of tumour size and aggressive characteristics and so make the tumours more curable by following radiotherapy and/or surgical resection.

Sadly due to the early failed experience of surgeons in using chemotherapy there has been a reluctance of many surgeons and other clinicians to re-look at the prospective value of using chemotherapy prior to planned subsequent radiotherapy or surgery and especially to use the chemotherapy by intra-arterial infusion or perfusion on a regional basis. In general surgeons lost interest in the use of the drugs and physicians in general do not have facilities for giving drugs on a regional basis. The integrated treatment programs therefore have been left largely in the hands of small numbers of dedicated clinicians combining the expertise of surgeons, medical oncologists, radiotherapists and others. New to this dedicated group are some relatively recent specialists, the interventional radiologists, who have become vital to the success of such a team. Interventional radiologists have expertise in putting cannulas into arteries in many parts of the body without requiring a surgical operation. The other essential professionals in such team work are dedicated nursing staff, experienced in observing the responses and potential problems that may arise in giving strong anti-cancer drugs into a localised region.

Such has been the background of development of integrated anti-cancer treatment for locally advanced and aggressive cancers. Better prosects of cure are achieved by such integration with effective chemotherapy as the first modality of treatment, to reduce the tumour size and aggessive characteristics followed by either radiotherapy or surgical resection, or both as the definitive follow up treatment to eliminate the reduced residual cancer.

The use of regional chemotherapy naturally depends upon the tumour being supplied with blood by one or sometimes more regional arteries which can be effectively cannulated for regional treatment and the likelihood that the cancer is totally contained in that region. Such cancers with regional blood supply and likely to remain localised in the tissue of origin and yet are commonly not successfully treated by surgical operation or radiotherapy are locally advanced cancers in the head and neck region (where there is one major artery of supply), cancers of stomach (again there is one artery of supply), and advanced malignant tumours in limbs (again with one major artery of supply).

Locally advanced breast cancers may also be effectively treated with a similar plan of integrated regional chemotherapy, radiotherapy and surgical resection but with this particular cancer there is also a considerable likelihood of tumour cells being more widespread into other body tissues. For such tumours and also for malignant tumours in bone (called osteosarcoma and common in young people) to achieve local response and local tumour erradiaction by using follow-up radiotherapy and/or operative surgery is only part of required treatment. These tumours are likely to have small deposits of cancer spread to other body tissues. For this reason additional post-operative adjuvant systemic chemotherapy is also given with considerable effect. In the case of advanced soft tissue sarcomas in limbs and osteosarcomas in limbs studies in Sydney University Surgical Oncology Service have shown that the standard treatment by limb amputation can now be avoided in about 80% of patients with equally good survival results. In the case of stomach cancer our studies have shown approximately twice the number of cures when intra-arterial chemotherapy is given first followed by operation than by operation alone.

There are other techniques for using regional chemotherapy, especially in limbs. By limited isolation of the limb from the general body circulation using tourniquets, very high concentrations of drugs can be delivered into the arteries for a limited period of time. Used in combination with tumour necrosis factor (TNF) such treatments have given even better prosects of cure of sarcomas and other tumours in limbs.

Other workers are exploring the possibility of using similar integrated techniques in treatment of tumours in the pelvis, especially in ovary, uterus, bladder and prostate. However at this stage more experience and information are required before

application of these combined and integrated techniques can be generally recommended or applied. Similar studies are being made with integrated treatment for cancer of the pancreas which is not only becoming more common in our community but remains one of the most difficult cancers to treat. Techniques are being developed to apply the advantages of regional chemotherapy by special techniques even though there are considerable difficulties in cannulating and treating the tumour-bearing area without damaging adjacent bowel and other tissues.

Cancers in tissue supplied by arteries which cannot be appropriately cannulated, but where results of standard radiotherapy and/or operative surgery are unsatisfactory, include lung cancer and cancer of the oesophagus. A number of studies are in progress to try to improve prospects of cure using of systemic chemotherapy preceding radiotherapy and/or operative surgery. Again although there have been some encouraging prospects, as yet there are still unsolved difficulties and results to date have not shown definite improvement.

SUMMARY:

In summary it should be stated that local malignant tumours which can be effectively treated by surgical resection or by radiotherapy alone or in combination are best treated by those standard treatment methods. This applies to most early cancers which are therefore best treated by appropriate surgeons and/or by radiotherapists. On the other hand tumours which are so locally advanced that they are unlikely to be cured by operation or radiotherapy, or tumours which are so locally aggressive that standard treatment does not offer good prospects of cure, or tumours for which standard treatment requires severe mutilation such as limb amputation; the possibility of improving results by the use of integrated regional treatment including chemotherapy (where appropriate on a regional basis) with radiotherapy and/or operative surgery should be considered. Such integrated treatment may offer significantly improved prospects of cure and without mutilation.

The former policy of patients being referred to one doctor be it surgeon, radiotherapist or medical oncologist for treatment by his or her specialised expertise only, should no longer apply when dealing with tumours with poor outlook from one treatment modality alone. Integrated treatment, much of which has been pioneered by the Department of Surgery at the University of Sydney, may well offer better prospects of cure.

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Award of the James Cook Medal to Sir Gustav Nossal
on 13 September, 1995, and his Address:

Medical Science and Human Goals: a Struggling Pilgrim's Progress

General Meeting No 1053 of the Royal Society of New South Wales was opened by the President, Dr D.F.Branagan, at 6.30 pm on Wednesday 13th September 1995 in the Rooftop Room of the Australian Museum.

The President indicated that this was a special occasion for the Society, and that it was his pleasant duty to introduce the speaker for the evening, & to award to him the Cook Medal.

The Cook Medal was first set up in 1947, & was funded by Henry Ferdinand Halloran, who had been a Member who had joined the Society in 1892 as a 23 year-old. Halloran was a surveyor, engineer & town planner. He did not publish anything in the Society's Journal, but he was a very enthusiatic supporter of research. Halloran funded what were to become the Society's two most prestigious Awards, the James Cook Medal, and the Edgeworth David Medal, the latter the Medal for young scientists.

The James Cook Medal is for outstanding contributions to science & human welfare in & for the Southern Hemisphere. The Society has made some 25 Awards in the 48 years the Award has been established. Only four of the Cook Medal Awards have been external to Australia: but they do include Albert Schweitzer. so I think he must have just got in because he did work close to the equator in Africa, but maybe it was just within the Southern Hemisphere.

We have only had one politician, that was Lord Casey, an engineer, but there have been several other engineers; we've had a chemist or two, agriculturalists, & we've had physicists; in all cases Australians of considerable calibre, but we've particularly had a predominance of medical scientists.

On the Epping Road at Lane Cove, on the way to the Society's office & Macquarie University, at this time of the year there is a particularly wonderful display of azaleas of the finest quality & in a variety of colours. But there are some that I suppose we could call really purple patches.

And when I look back at the Cook Awards I notice that there have been at least three purple patches in the Awards through staff at the Walter & Eliza Hall Institute in Melbourne. They are, of course, first, Sir Frank Macfarlane Burnet, who was awarded the Medal in 1954, and more recently Dr Donald Metcalfe, for cancer research. It's certainly an impressive record, I think, for the Institute, which of course has an unparalleled renown in Australia.


Sir Gustav Nossal FRS

Tonight, Sir Gustav Nossal is the third, and I hope that in ten years' time his protege will be here to follow on the story. I don't think I need to go into Sir Gustav's long & illustrious career: I suppose I can say that he is a Sydney University graduate: he has come from this fair city. He became the Director of the Walter & Eliza Hall Institute in 1965, & Professor of Medical Biology at Melbourne Umiversity. He is currently President of the Australian Academy of Science, & he is a Director of the CSIRO & of a number of

companies. He is Chairman of the Scientific Advisory Group of Experts on the World Health Organisation on Global Programs on Vaccines. He is a Fellow of the Royal Society, and was awarded the CBE in 1970, KT in 1977; he is a Member of the Prime Minister's Scientific Council.

He has other interests: he has been involved, of course, in the Felton Bequest, in the Gallery in Melbourne. But unlike the original donor of the Cook Award, F.H.Halloran, whose recreation was motoring, Sir Gustav's recreations, he says, are literature & golf. I'm not sure how good at either he is; he says he is promising to get into literature, at least in the scientific sense, in the next few years: & I won't ask him about his golf handicap!

I think without further ado I should present Sir Gustav with the Medal: on the reverse side the medal reads:

"Physical Science, Biological Science & Social Science" with a map of the Southern Hemisphere; on the obverse side:

"The James Cook Medal for Outstanding Contributions to Science & Human Welfare in the Southern Hemisphere
"Awarded to Gustav Joseph Victor Nossal KT, 1994, by the Royal Society of New South Wales"

It is my great pleasure to present this Medal to you.

Medical Science and Human Goals: a Struggling Pilgrim's Progress

Mr President, distinguished Members of the Royal Society of New South Wales, Ladies & Gentlemen: this has been a particularly moving introduction, and a very, very special occasion for me to be back here, in the city that never leaves your heart once you have grown up here, and in particular to be receiving this award under the Presidency of this distinguished person, of my old University mate, David Branagan: we have been good friends for forty years, and its absolutely wonderful to be receiving this award under his Presidency.

I should immediately state, of course, that it is very wonderful to have the chance of thinking about James Cook: really he was a medical scientist! Long after the controversy about who really did discover Australia is over (and it wasn't Cook), people will remember him as the discoverer of vitamin C, and the prevention of scurvy on those many long boat voyages. And indeed his tremendous enthusiasm for science (he sponsored Banks and many others) makes him truly one of us in science. I think he would be extremely pleased about the giving of this award to scientists and to those interested in science down the years. It is a tremendous honour to receive this medal with its distinguished history: and I can only say it is immensely humbling.

Now having said that, I thought to myself you might all find the title of my talk a little bit self-indulgent: 'Medical Science & Human Goals: a Struggling Pilgrim's Progress'. Why did I choose such a sentimental-sounding title? Well, I got to thinking that this medal would probably be the last award which I would receive before my retirement in eight months' time. Its been a long ride in the Walter & Eliza Hall Institute: as a matter of fact, it was thirty years as Director just eleven days ago, on the 1st of September, 1965, when I took over, and now it's coming to an end. I got to thinking about what does it all mean? You know, what has my life been about?

And I came to the realisation quite quickly that society at large has only the dimmest of outlines of what a medical scientist actually does, and of where medical science sits in the great spectrum of national development & world health. So I thought it would be quite good fun, albeit a bit self-indulgent, to sketch the pilgrim's progress, to tell a little about where it all began, to tell you a little bit about what I think is important, and where it may be headed. And I have a subtitle for the Address: the subtitle is called: "From Molecules to Persuasion".

To give you a sort of glimpse of what I would like you to take away, I actually believe that medical science is a seamless web, and to improve the health of humanity, including our own citizenry, we will need everything: from molecular science, the understanding of DNA, and the biochemistry & genetics of the cell; & the physiology of bodily systems, which has been my main line of activity; through the more applied sciences of pathology & clinical medicine; and right through to the very applied population sciences of epidemiology & public health. You need all these in order that the discoveries speed their way to as large a proportion of the citizenry as possible in the shortest possible time-frame.

So roughly speaking, I want to divide the talk into three not quite equal thirds: I will talk a little bit about the science that I've done. That's going to be a touch hard, but I promise you it won't take more than fifteen minutes. There's got to be a bit of science in a talk like this, or it would be trivialising the occasion!

Then I wanted to talk for a while about what this great science of immunology means for the world, in terms of the total population, not that one-third of a percent of it which lives in Australia, or indeed that approximately one-sixth of it which lives in the fully-industrialised world.

And then lastly, I want to talk briefly about the work that still has to be done, when the medical scientist & the medical professional have finished, before the society at large can benefit from anything that happened.

Early Motivating Influences

I want to set the scene by describing in just a very few minutes how I even got to thinking about medical science. I had started medical school in 1948, and there may be a few people in the room who might remember that at that time we only had five years of secondary education in New South Wales. So I was a little young starting, all of sixteen years old when I entered medical school: just imagine that, making a decision about what you are going to do for the rest of your life at the age of sixteen! Amazing to think back on.

And we had in 1948 probably the height of that big wave of repatriated soldiers, who were the ex-service men & women, who swelled the year to a very large size. Now, I remind you, there was no quota in those days: anyone who passed the Leaving Certificate examination, or to be quite precise, who matriculated, which meant you had to get five subjects (four subjects would pass you, five subjects gave you matriculation), anyone could get into medical school. And so we were six hundred in first year.

We had a rather profane medical student song which had as its refrain '50% must fail, 50% must fail'. And it was actually literally true, because in fact in second year we started anatomy: that was the main subject, and the main way of learning anatomy was carving-up the human body. And there were a maximum of thirty-two students to a body. So you can work out the sums: with a few slippages from second year, and second year repeats, they could only pass three hundred of us, because there were only ten tables! Eight people to a quarter body, trying to carve it up, when I think back, was really quite ridiculous.

So 50% indeed did fail, and when I woke up & recognised that I was really now a uni student, I was already in the third year! By then I was eighteen, and sort of getting out of childhood & into adulthood. And a group of us from what you might call perhaps the brighter kids in the class, said 'listen, this is no good, we're not learning anything: if we're going to learn anything, we're going to have to teach ourselves'. Which is probably not a bad adage to take through life, if you think back: you know, the best learning may be that which you do for yourself.

So we started in this little group to give each other seminars: that is to say, one person might read up, for example, how blood cells are formed; another person might read up about the Krebs cycle & intermediary metabolism in cells & biochemical features; and a third person might read up the latest thing about Jack Eccles' work on the nervous system. And we would read into these topics, & then give it in very digestible form to the six, eight or ten kids that formed this particular study group, the end result being that we did pretty well in the exams if one of those topics perchance turned up! Of course, if it didn't, it was just for our own interest & so forth. This process of digging into the medical literature gave me a real feeling for research.

Two other things things contributed to my choice of science. First, I had an elder brother who had done science, not med., & had become a biochemist. He was quite a few years older than myself, and of course you tend to hero-worship your elder brother. He had moved to Adelaide, but he always used to bring back friends for the ANZAAS Meetings. In those days in the 'forties, ANZAAS was a big thing: it was THE national science meeting. And these people would come & stay in our family home. My head, as a thirteen or fourteen-

year-old kid, would be buzzing with the wondrous researches that these people were doing. And that helped too.

So in the event, I took a year off to study viruses at Sydney Uni, under a chap called Pat de Burgh, a Senior Lecturer in Bacterioiology. He was a virologist, a very clever man, and during that year (he only had two students doing this Bachelor of Medical Science course) he took us down to Melbourne & we spent three days at the Walter & Eliza Hall Institute, one day at the Fairfield Infectious Diseases Hospital, and one day at the Baker Institute: three of the great centres of medical research in Australia. And I guess I got hooked during that week. I found that so fascinating that, at the ripe old age of twenty-one, by now, I said 'gosh, I've got to give this thing a try'.

But life had stored up one funny little surprise for me: you see, I thought this business of the viruses & the biochemistry would be my life. Now, why viruses? Because they were the smallest form of life. And why biochemistry?

Well, it was a little before DNA broke, but I really thought biochemistry would turn out to be the king of the sciences, of the life sciences, because it was the most basic. That did indeed turn out to be true, except now they call that branch of biochemistry 'molecular biology', which word had not been coined in 1952.

So here was I, seeking to discover all the secrets of the life process by becoming a biochemical virologist. What could be better than to sit at the feet of the world's greatest virologist, Mac Burnet?

In 1957, I tiptoed into his lab, having graduated in medicine, done my residency at Prince Alfred Hospital for a couple of years; all my friends thought I was mad to go & do this research business. Why, with another two years you could have become a Member of the College of Physicians, & you could have become a cardiologist, & put your shingle up on Macquarie Street, & it would have been fantastic: they all thought I was absolutely crazy to go into this research business.

But I tiptoed into Burnett's lab, only to find out that he had switched his interests from the virus, the cause of many diseases, to the immune system, the immune defence system which fought the virus diseases.

To be frank, I had absolutely no interest in immunology, none whatsoever! But the die was cast, I had set my life to moving down to Melbourne, with my wife & tiny little baby daughter. Hence I was perforce an immunologist!

So, you know, things happen in strange ways: my brother being a biochemist, Pat de Burgh being a biochemical virologist, my meeting Burnet at such a young age, & hearing him talking about the polio virus & the polio vaccine. Fantastic stuff for a twenty-one year-old. And here I am, the virologist perforce turned immunologist.

Discoveries in Cellular Immunology

The big problem in immunity was the number of things you can become immune to. The vast diversity of antibodies, each capable of recognising portions of different bugs. And, you know, that had been known for a long time. But then along come Watson & Crick, and they tell us that DNA is the master molecule, and they tell us information is carried in DNA, and it can't be carried into the cell by a foreign invading germ, by the proteins of a virus or a bacterium.

So three people: Niels Jerne in California, David Talmage in Denver, and Mac Burnet in Melbourne, came up with this theory, for which Mac Burnet received enormous credit. The theory said that the antibody molecule is not shaped or patterned as a template against the vaccine molecule, the antigen. Rather, it is pre-formed in the body existing as a receptor on the surface of the cell. All that the antigen then has to do is to come & stimulate the right cell, and then through mutation afterwards, a really good antibody would be formed, exactly congruous to the antigen.

I said to myself, gosh, this is a bit crazy. We'd all been brought up to think that this direct template notion, which had been around for about twenty years, & had been backed by the great Linus Pauling (one of the few people to win two Nobel Prizes), must be correct.

Burnet challenged me to think again, and I said 'I think we can disprove this very quickly: I am considering immunising a mouse or a rat with three different vaccines (three different antigens, to use the technical term), get the antibody-forming cells from the lymph node or from the spleen of these animals, and very quickly show that each cell will produce all three antibodies'. Now if that's true, Burnet's clonal selection theory is dead. It was a Popperian situation: I could perhaps disprove the new hypothesis.

Well, of course, there weren't any methods for studying antibody formation by single cells, and I had to invent those, and fundamentally, we came to a pretty simple conclusion, and this will appeal to many of those of you who are physicists or chemists, & understand the law of mass action.

If only one cell is producing antiboby in tissue culture, and you were to put it into, say, one mil in a test-tube, of course the antibody formed would be extremely dilute, and you would never detect it. But if in point of fact you could confine the environment into which the cell puts out its antibody to a tiny little droplet, of perhaps a ten millionth of a millilitre in volume, then the antiboby titre, as we call it, the antibody concentration reached at the end of a four hour or twenty-four incubation period, would be exactly the same as if we'd put 100 million cells into 10 ml, because it's a question of concentration. So we could get a high concentration of these antibodies into these tiny, tiny little droplets, which we stopped from evaporation by surrounding them with mineral oil.

And then we used as a titration method, an antibody detection method, a very tiny number of motile bacteria, instilled into that droplet by micromanipulation, which, if any antibody were present, would immediately stop swimming & begin to clump; if no antiboby were present, then they would swim happily for half an hour, after which you would terminate the experiment.

The resulting thing was, that one cell always formed only one antibody. The first little step had been taken towards suggesting that this clonal selection theory (see Fig.1) could indeed be true. Just a little side-light to history: we worked on antibody formation by single-cells for about five or six years, but we weren't clever enough to recognise how brilliant it would be if we could immortalise those antibody-forming cells by fusing them to a cancer cell.

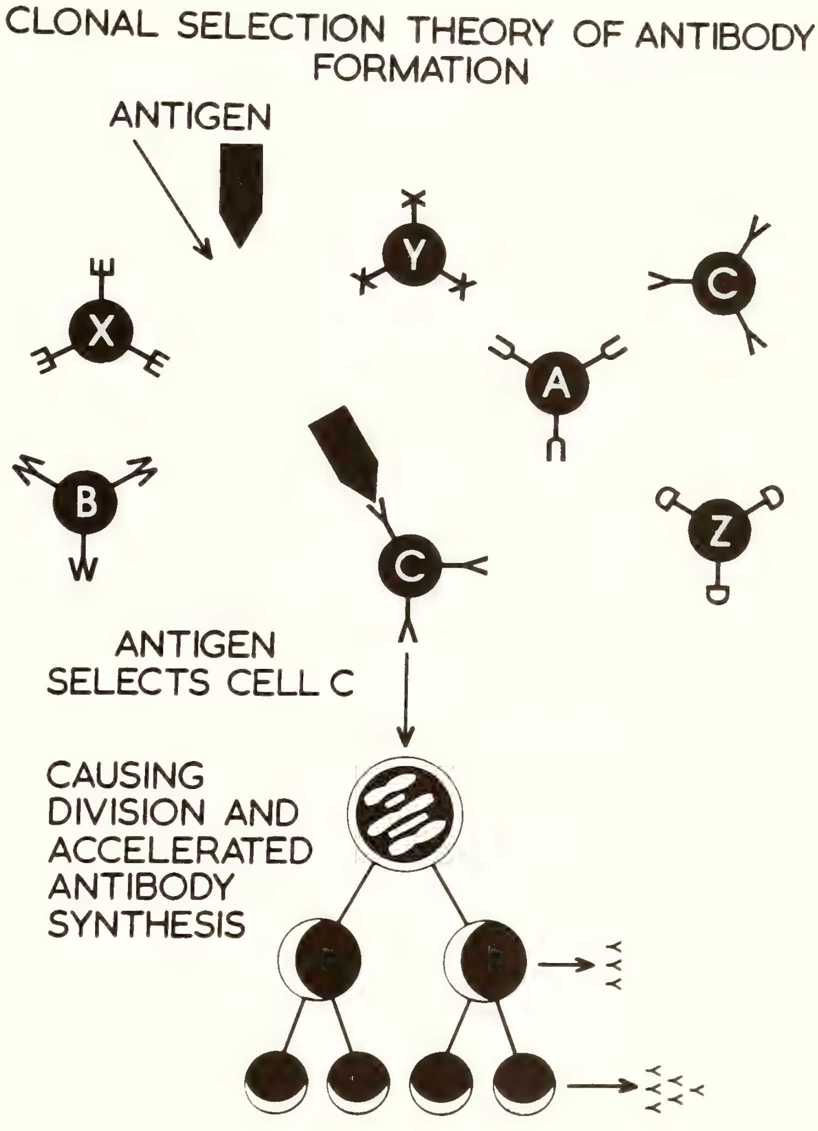

Fig.1: The revolutionary aspect of the clonal selection theory of antibody formation was that it saw the antigen only as selecting a cell with a corresponding receptor, not as carrying new information into the cell.

And that is exactly what Milstein & Kohler did, for which they won a Nobel Prize, and for which you now have monoclonal antibodies that are widely used in diagnosis, in therapy, & in industrial applications. One of the greatest tools of modern biology is monoclonal antibodies.

We laid the groundwork for that work: we did the pure science, but we didn't do the applied science. H+ence the seamless web, the need to continue this matrix of scholarship all over the world.

I should go on to say that the very fact of this highly diverse repertoire of antibody genes & antibody-forming cells, means that every single cell makes antibodies that are a little bit different. And hence the monoclonal antibody has a razor-like precision of recognition: that's what determines its special properties.

The next thing we did was to say 'well we've got to disprove this direct template hypothesis more clearly'. What we did was to make the antigen very highly radioactive with an extremely high specific activity of radioactive iodine, which was a convenient isotope for registering on photographic film. And we injected this very hot antigen in limitingly small amounts into rats (see Fig.2). Then we performed what we call an autoradiograph: it was really taking an X-ray on a single cell, basically.

Wherever the isotope goes, you get a little dark silver grain in the photographic emulsion that you've applied to the cell. An antigen-containing cell would be black with dots on it. A cell without antigen would have no developed silver grains on it. We went through hundreds of single cells and finally proved that these cells had no antigen in

them. In point of fact, we could have detected easily four molecules of antigen in the cell, and we found absolutely none. So the direct template hypothesis was untenable as there is no antigen in the antibody-forming cell to act as a template.

That actually rated a fairly sizable story in the New York Times, about half a page, and it is an interesting reflection on U.S. science journalism that so much publicity can be given to a totally basic-science discovery.

We went on (and you won't believe it, we took a total of eighteen years from the first experiment to the last) to provide a formal proof of the clonal selection theory.

We did this by actually fractionating normal lymphocytes, normal white cells on antigen layers, recovering a tiny fraction (one cell in ten thousand or one cell in 100 thousand) capable of binding that antigen. We could then culture, in single-cell microcultures, the antigen-specific cells, and we could prove that the only antigen against which those could form antibodies was the antigen that had been used in the fractionation procedure: it couldn't form antibody to anything else.

So here if you want, in a totally un-immunised animal, we found the needle in the haystack, we found that one cell that would make that one antibody, ready with pre-formed receptors.

A very important thing happened when Jacques Miller joined me, another Sydney University graduate, who had been working in London for quite a few years; Miller was an expert on the thymus, which is the big lymphoid organ in the chest; and I had been working a lot on bone marrow.

Miller, Warner, Szenberg, Mitchell and others worked out that the white cells in the blood, which we call lymphocytes, the cells of your immune system, belong to two great families: those thymus-derived, now called T-lymphocytes; and those bone-marrow-derived, called the B-lymphocytes. The thymus makes T-lymphocytes, bone-marrow makes B-lymphocytes. They leave these organs and reach the lymph-nodes & spleen and the circulating blood, and this is your defence army.

The two types of cells do two entirely different jobs: the B-lymphocytes make antibody: they are the cells that go wrong when you have agammaglobulinemia, which you treat with injections of gamma globulin. The T-lymphocytes, on the other hand, don't make antibodies, but they do mediate a strong inflammatory response.

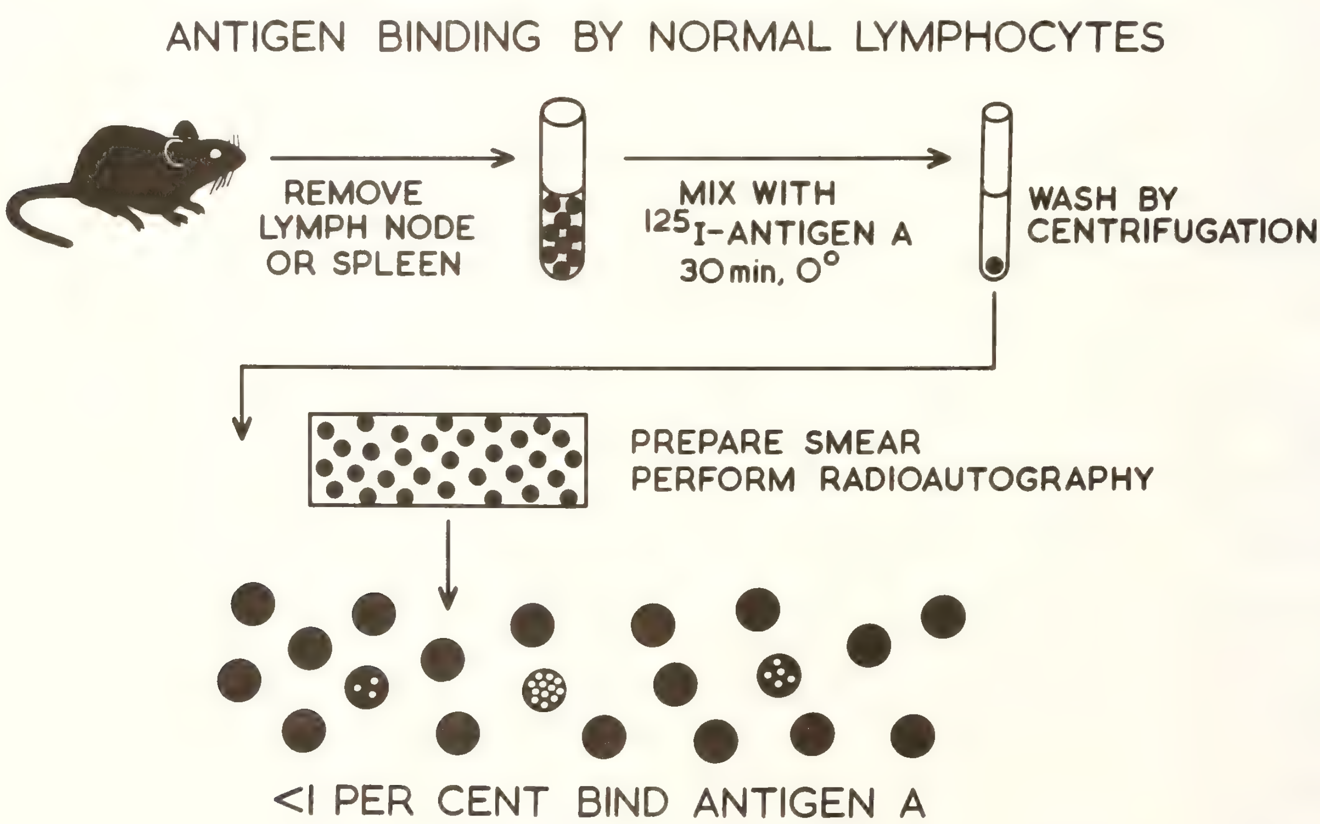

Fig.2: This experiment shows that normal B lymphocytes are very heterogeneous in their capacity to bind a given antigen, antigen A. The great majority of cells do not bind at all. Some bind it just a little bit. Only a very occasional cell (perhaps 1 in 10,000 or 1 in 100,000) binds with high affinity. If this cell can be separated, culture experiments show that it will form antibody to antigen A.

Think of the B-cell as a policeman with a gun that can shoot an enemy at a long distance: a B-cell-making antiboby in the lymph-node could kill a small-pox virus entering via the big toe, because the antibody moves in the blood-stream.

The thymus-cell, the T-cell, is more like a wrestler, who wrestles a foe in close combat by direct cell contact. It turns out that the T-cells are particularly important in viral infections, because they are capable of killing virus-infected cells, and therefore of cutting short an infection, and stopping the spread from cell to cell. T-cells also fight infections by promoting inflammation and strengthening the action of scavenger cells. One kind of T-cell is the target in AIDS.

We found out two more things: we found out that the T-cells & B-cells had to collaborate in order for a good immune response to go forward; and we found out ways of distinguishing and separating the different kinds of lymphocytes.

Now are you beginning to get the drift of my story? Here was research that was genuinely the purest of the pure. Our purpose was solely to find out how the immune system worked: how cells make antibodies; how the genetic code works in terms of antibody formation; what the thymus contributes to immunity; what the bone marrow did; how the cells interacted with one another: pure science, with no applied intent.

Along comes something like the AIDS virus, but because of this prior work, and of course, a lot of other work from around the world which I haven't had a chance to mention, it is possible to understand the AIDS virus, define its target, and grow it in the test-tube. Had that prior basic knowledge not existed you would never have been able to grow the AIDS virus, and nobody would have been able to develop immuno-therapeutic AZT or DDI or any of the other drugs, nor would you have had a chance to create experimental vaccines. Unfortunately we do not yet have an AIDS vaccine about which we can be confident.

So, basic science, applied science, the seamless web.

Now, the last thing that I want to say in terms of my own scientific work, is that to the immunity, there is a mirror image. You make antibody to lots of things: you make antiboby to viruses and bacteria, you also make antibody and a strong T-cell attack to someone's kidney graft, if I choose to place a kidney graft in your body in order to cure your chronic renal failure. We have to use drugs to keep that immune response at bay. But you don't make antibody to yourself.

Now there's a deep puzzle here. Why should another person with the greatest of vigour reject my kidney, no matter how carefully stitched into his body, and why should that person so readily allow his own kidney to live without rejection? There's got to be some principle behind that.

We've also now worked on this subject of immunological tolerance (see Fig.3) for, well, in my case, thirty-eight years; and we've got a long way towards determining the secret of how it works. When I say 'we', I must immediately add that it was really the global peer-group.

Tolerance, the capacity to tolerate yourself, is the opposite of clonal selection. It is in fact a negative action of antigen when it acts on the white cells under certain circumstances. And it comes in two flavours: either an actual physical killing of the anti-self cells, or a non-lethal regulatory signal, which I termed 'clonal anergy' in 1980. To my great pleasure, that word has stuck, and we now recognise these two forms of tolerance, anergy & deletion. Right at the moment, my main work is actually in tidying up the exact difference between those two.

Vaccination and Other Practical Goals: Association with WHO

I want to move on to the next stage, because that's all a little bit technical.

Round about the middle to late seventies, I became very impressed with the selfishness of what we were doing. I thought to myself 'O.K., here I am running the Hall Institute, here we are doing all of this basic science, here we are having fantastic fun, we're actually becoming world-famous (I shouldn't say it, but it's true), doing this basic science, which has given us a lot of pleasure. But to the extent that we're working on diseases: on multiple sclerosis, on leukemia and other cancers, what in fact were we doing to be true to the Pasteurian heritage? What were we doing about vaccines, what were we doing about tropical diseases, what were we thinking about the third world, what were we doing about poor countries? The answer was nothing.

So I did two things: I started a large program under Dr Graham Mitchell at the Institute, which I won't talk about today, which is searching for a malarial vaccine, and which has now reached the stage of

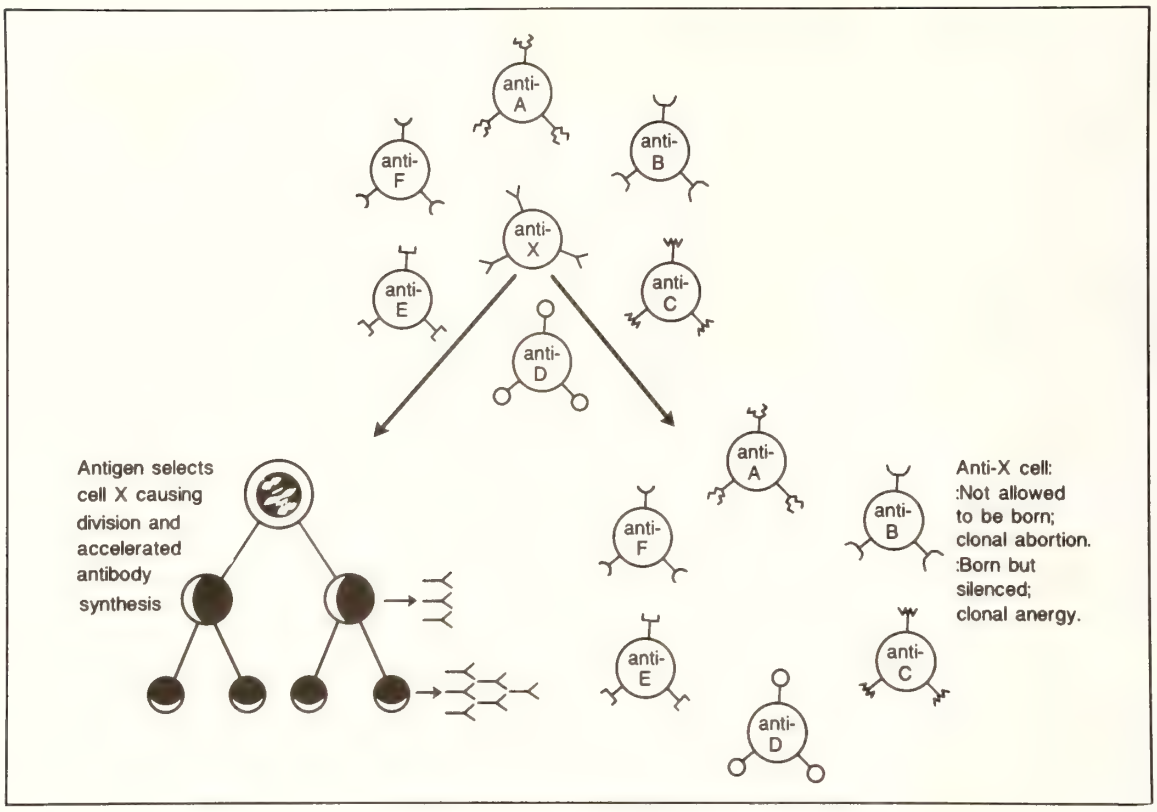

Fig.3: Immunological tolerance (right-hand side of the diagram) is more or less the mirror image of clonal selection (left-hand side). If the antigen encounters the lymphocyte population while the latter is still immature, as would be the case with a self-antigen, the cell is either deleted or rendered anergic.

early clinical trials: we then hope to go into larger field trials, either late this year, or, more probably, early next year. So the malaria vaccine work has been slowly rumbling along as an effort that we started in direct response to this pain in my breast that we hadn't been true to the Pasteurian heritage.

And the second thing I achieved was, through invitation, to become tied up with the World Health Organisation. And I'm now the Chairman of what they call the Global Program on Vaccines & Immunisation. And this program has three components:

First is the delivery component, called EPI, the Expanded Program on Immunisation, the naked aim of which is to get the common childhood vaccines, which all our kids get, to every single one of the one-hundred & thirty million children that are born into the world each year. That's an amazing goal, isn't it? A suberb challenge to meet this aim. Now that of course means that we have to have, for all the world, vaccine supplies & vaccine quality control.

The second goal therefore is to work out politically how to transfer the technology to some of the larger third world countries, such as China & Indonesia, enabling them to make at least some of their own vaccines, and somehow to make sure that we haven't got two classes of vaccines, one with good quality control, and one that may be inferior.

The third and very important goal is Vaccine Research & Development, or VRD: more vaccines, particularly for diseases where we don't have vaccines yet. This third component in its turn has three components:

First, to promote the development of new vaccines of importance to the world, and prepare for their introduction into the Expanded Program on Immunisation; secondly, to simplify vaccination procedures; and thirdly to develop cheap & simple new diagnostic tools.

In regard to the second item under VRD, vaccination procedures, my colleagues in WHO have a slide that looks a bit like St Sebastian: its got arrows sticking all through, except that the arrows aren't arrows: they're syringes with needles. We can't have children looking like pincushions. Our own children have already received a lot of vaccination shots by the time they're eighteen months: they get their DPT at 2 months, 4 months, 6 months. Polio is fortunately given as drops.Then they have measles, mumps & rubella. Now there's the excellent meningitis vaccine.

Imagine if we had twelve more other good vaccines, we could get into a consumer revolt, even in the developed countries, let alone in an African village, where you might have to walk five miles to get to the little station where this vaccine is given.

So simplified vaccination procedures are very much required.

As you come close to the total eradication of diseases (and that is very close for polio, could be a reality for measles, and is a reality, of course, as you all know, for small-pox), before you can cease vaccination, thereby saving huge amounts of money, you have to be damned sure that it's completely gone. For that you have to have excellent surveillance mechanisms.

And thinking of remote African & Indian villages, that means cheap & simple new diagnostic tools, the third item listed in the Vaccine Research & Development agenda.

The Expanded Program on Immunisation

Now a few words on the Expanded Program on Immunisation. There are seven vaccines that are supposed to be going to all the children of the world: diphtheria, pertussis, tetanus, polio, measles, BCG for tuberculosis, and hepatitis B.

We in Australia do not use the tuberculosis vaccine for two reasons: there isn't much TB left, thank God (but it could come back); and also the BCG is not as good as it should be (there is a requirement for more research & development of a more satisfactory TB vaccine). Vaccine for hepatitis B from 1995, according to the World Health Assembly should be going to all countries with a high carrier rate. Vaccine for yellow fever is also required in some countries. The program has made great progress in polio myelitis.

In the Peoples Republic of China, where the birth cohort is 23 million children each year, they had one case of polio in 1994, one certified case: remarkable progress. And we have set our cap at global polio eradication by the year 2000. A very tough task! A very difficult goal to achieve: it will, as with smallpox, be Africa that will be the hardest nut to crack.

We have some countries both in Africa & in the Balkans where civil strife could frustrate the procedure, but we are making really excellent progress. And you imagine the world without polio, you imagine the world where no-one has to get the polio drops any more, and it's been estimated that the net present value of polio eradication is thirteen billion US dollars. The costs, we believe, to get this point will be a hundred million a year extra to what we've got each year between now and 2000.

Immunisation coverage over this period has gone from 5% of the developing world to 80%: but unfortunately I have to tell you it appears to have have stalled then, and the last 20% are going to be very difficult to get.

The plan was for 95% reduction of measles deaths by this year: there has been a very significant reduction of these deaths, probably not quite to the 95% of the 2 to 3 million deaths per year that is "normal". All told, vaccines prevent 3 million deaths per year, but 2 million vaccine-preventable deaths remain. Sixty percent of the deaths which the present vaccines could stop are being stopped, forty percent of them are still eluding us.

Now what's the total picture?

There are 12 million deaths of children in the world each year: 9 million of these are due to infectious communicable diseases. Only one quarter of the pie is accessible with present vaccines. We have three quarters of the deaths from diseases for which no suitable vaccine has yet been made.

What are these diseases?

The biggest killers are two-fold: the diarrhoeal diseases, both bacterial and viral; and accute pneumonia of infants, which is particularly a problem in our own part of the world, where, in Papua-New Guinea, for example, pneumonia beats malaria as the number one killer. Malaria is a further enormous problem: there are somewhere between one & two million deaths per year from malaria each year.

If you pool both childhood & adult deaths, there are nearly three million deaths per year from tuberculosis. I think that in itself shows that the BCG is not doing a good job. We have to do a lot better. And consider the number of deaths from measles: 2 to 3 million per year. One reason is that the current measles vaccine is not active in very young children, and the second is that measles and bacterial complications from measles are much more serious in a third world setting.

Measles is immuno-suppressive, and the immune response is not good for about a year after the attack, or not as good as it should be. That means that if you're under-nourished, and if you are in a situation of constantly being exposed to infectious micro-organisms every single day, your resistance will crumble, and so

this overall measles death incidence is about 2 to 3 percent; it's still not high, but when everybody gets a disease, you can calculate what the toll is.

Now, the existing measles vaccine is much less efficient when antibodies of maternal origin persist at the time of immunisation. I've told you everyone gets measles, right? They've either been immunised or they've had the disease, so Mum has antibodies. Those antibodies cross the placenta, enter the foetal blood stream, protect the child against measles over the first four months of life.

But then, gradually, the maternal immunity wanes; and the vaccine doesn't take too well before 9 months, even in developed countries. So we have a blind period and many unprotected infants. We have to devise a measles vaccine which works in the presence of low levels of anti-measles antibodies derived from the mother.

Now, another important development would be a single-dose tetanus vaccine. But why? Well, I've told you that this EPI program is new, and I've told you that, previous to its existence about 10 years ago, vaccine coverage was 5% in the developing countries. This means that young mothers-to-be aren't protected against tetanus. Right?

So, they have their babies, in a little African village, where there have been domestic animals, where the hygienic conditions are not good. As you all know, tetanus spores (a) live for a long time, (b) are carried in animal faeces, or human faeces for that matter, and they can remain in the ground for a long time. End result: neo-natal tetanus: when the little baby is born, it gets tetanus, it dies of lock-jaw, with the horrible frothing at the mouth, that we now only read about in text-books; that you maybe have heard as horror stories from some older uncle or grandmother.

Now we've got to stop that: and we've got to catch these pregnant women, but we may not be able to get them to come back for three injections. And actually, they certainly need three, they may perhaps in fact even need four, depending on where in the world, and how good the vaccines are, and so forth.

So we need a one-shot vaccine which gives a lasting effect to simplify the vaccination schedule. And that is, as I say, overall, quite apart from tetanus, a very big goal in our research program.

Applied research: not very glamourous, not nearly as Nobel-Prize-winning as monoclonal antibodies. But this applied research is enormously important.

And so we come to vaccine combinations: we come to new ideas about immunising via mucosal surfaces. We come to oral vaccines: easier and cheaper; no needles, no need for sterilisation of syringes; no AIDS transmission, no hepatitus-B transmission, if your autoclaving equipment breaks down. Of course disposable needles & syringes are the ideal, but sometimes difficult to achieve in a third world setting. A very new idea is nucleic acid vaccines, which we won't be able to go into tonight. Oral vaccines are certainly one simplification of vaccine delivery.

From Molecules to the Persuasion Game

So much for the responsibilities that I think we carry for the third world. But I want to end up on a surprising note, a note which you might find a little bit unusual.

I've actually come to the view, over the last seven or eight years, that the medical science, and even the public health application, such as these public health vaccine programs, are only two-thirds of the story: the final third of the story relates to human behaviour.

Now, let me surprise you: you believe that smoking rates have gone down: they have: 30% of the population still smokes, and that's 45 years after Richard Doll first showed that smoking causes lung cancer, and 30-plus years after it was shown that smoking was responsible for much of heart disease. We're only just now starting to see the down-turn of lung cancer rates in men, in Australia, and we have not yet seen the end of the rise of lung cancer deaths in women: it's still rising.

That's what I mean by persuasion. You can't just be a scientist: you've also got to be a marketer: you've got to get your ideas across to both the profession and the public at large.

I wanted to talk for a moment about STD's. I think Australia has done a wonderful job in STD's; but the pressure has got to be kept up.

We cannot be complacent, we have to keep investing, we have to keep spending money to keep AIDS out of the heterosexual community, and to continue to reduce its impact on the gay community, and on the intravenous-drug-using community. It's got to be a persuasion game, it's got to be a case of smart marketing.

Let me tell you a story about vaccines. There's a new vaccine, which your kids & grandkids are getting. It's called HiB. It's the vaccine against the worse of the two forms of bacterial meningitis: a

wonderful vaccine. Efficacy rate in the high 90's, side reactions virtually unknown.

And we're doing a good job in introducing it: but the most brilliant job has been done in the United Kingdom, where they blitzed the population with an expensive media campaign, a little akin to our road accident campaign in Victoria, which you may have heard about: the horrendously graphic ads which showed the effects of drink driving & the effects of speed, and which in their way have made Victoria the leader in the world in reduction of traffic deaths.

So we've got to be marketers, and we've got to get into the persuasion game, and we've got to take public health and preventive medicine very seriously. Right at the moment, you & I are spending eight & a half percent of this country's Gross Domestic Product on health. But of that, 97 to 98% is spent on the sick now, here & today's sick. I wouldn't deny the genuine demands of those sick today.

But we very rarely think about public health, preventive medicine, positive health promotion, health education; the simple things: avoidance of smoking, avoidance of substance abuse, eating a healthy diet, getting a very diversified diet, having your blood pressure checked regularly, having a mammogram, having a Pap smear, and possibly, as the next major step, the introduction of fibre-optic sigmoidoscopy for the early diagnosis of colon cancer.

These unglamourous things, actually very straight-forward, on which we spend the two or three percentile, can have a major impact on mortality & morbidity, and are in many ways a much more appropriate expenditure of the health dollar.

But you see, its tough, because when grandma's sick, let alone when a child is sick, you'll pull out all the stops. There is nothing that you won't do to urge the politicians to build that extra liver transplantation unit or two, somehow make sure the district hospital doesn't close, or somehow doing something for the one already sick.

The more cerebral activity of preventing the 30 years of pathology which leads to coronary artery disease, through a healthier diet & exercise, and keeping people of a reasonable weight, that doesn't grab the public imagination nearly as much.

That's why I need to talk about it with you, that's why I'm absolutely delighted that our friend from the 'Australian' is taking avid notes, because this is really important. We've got to redress the current imbalance between acute crisis medicine which uses high-tech intervention, for people who have been harbouring pathology in the body for thirty years, and the future, which depends on research, the search for better cures, and on education for preventive medicine and public health. Thank you very much.

(Applause)

President: Thankyou, Sir Gustav.

<u>Questions from the Audience</u>

President: Sir Gustav has indicated to me he is certainly prepared to answer questions & take on discussion: I'm sure there will be many who would like to take advantage of this.

Dr F.L.Sutherland: If you are reducing infant mortality, by the vaccination program, does that not create a bigger population problem to the world?

Sir Gustav: It's a very important question, fortunately it does have an answer: in the 25 years or so since I have been interested in world health, I've talked to literally dozens, if not scores of people from the developing world, and people interested in the development process.

They are absolutely unanimous on one thing: that is that you can sell birth control only in the context of maternal & child health. If you can guarantee a woman she will have a healthy child, and if you persuade the woman that spacing the births will add to that child's health, you have a chance.

If you attempt to control the human population by high death rates (really, in a sense, what you're saying: doing something that doesn't reduce the death rate, but maintains a high death rate), the sheer answer is that people over-compensate, and more particularly do they over-compensate since the green revolution has produced plentiful foodstuffs in most of these countries (even India is now a net exporter of food: if you remember thirty years ago how many famines there were in India).

So as countries leave true poverty, and begin to enter newly industrialised status, the pattern has always been exactly the same: reduce the infant mortality rate, and your birth-rate will come down at an increased rate. Increase the death rate, be it by famine or pestilence, and human beings over-compensate, because, don't forget, there is no social security in these countries. The only guarantee for your old age, which

probably hits you in the '50's is your living male children. So wouldn't you too guarantee that you'd have a little bit of redundancy left, so that you don't starve when you're old & you can't work any more? And that is absolutely clear-cut.

It's a hard one to explain, I mean, it's a bit counter-intuitive: you say, O.K., population size is a mixture of birth-rates & death-rates: there's two ways of controlling this: increase the death-rate, or decrease the birth-rate: the fact of the matter is, increasing the death-rate doesn't do it.

Lady questioner: Is there any work on a birth control vaccine?

Sir Gustav: Yes, a lot of work. The answer is: there is right here & now a birth-control vaccine: it is a vaccine directed against the hormone human chorionic gonadotrophin, which is produced by the ovary in the first few days of pregnancy (it is produced actually as the ovum travels down the Fallopian tube): it's absolutely essential for implantation of the fertilized egg in the womb.

And that works: it doesn't work perfectly: it's been primarily trialled in India, and it's reversible. It doen't seem to have any side-effects, but the problem with it at the moment is that it only works in women who get an antibody titre over 50 nanograms per millilitre, and only 70% or so of the women at the moment do that.

So you cannot say to them "go away & have unprotected sex": you've got go & say to them "come back to my tent & have an antibody test": and that just won't work in a field situation: antibody tests for everybody are just far too expensive. So there is need for a stronger vaccine.

There's also a male vaccine which is being developed in India. It is not permanently sterilising, but it attacks the outer coating of the sperm, and makes the semen essentially sperm-free; and it works in cattle.

Now, whether you going to get that accepted in the human setting (knowing what the male of the species is like) I don't know.

But it is working in a veterinary setting, and it's being strongly promoted by some of the more liberal elements in India to reduce their terrible problem of the sacred cows, wandering around & eating all the food, & not being able to be of use for anything. And there are many people who say a male vaccine will be required, and I think this is an alternative.

I actually believe that for women (and men, but the burden seems to fall chiefly on women) to have the total control over their own fertility will demand a variety of techniques, suitable to different ethnicities, to different physiologies, to different religious beliefs, & to different cultural patterns. And we have seen very clearly with the pill that slavish adherence to one method only isn't going to do the trick, at least not for a life-time. Certainly birth control vaccines will have a place in the future.

Dr G.C.Lowenthal: What about the effect of HIV/AIDS? Presumably the effect of it will be found in time to reduce populations? Is there a development in the resistance of the virus to drugs?

Sir Gustav: Yes, this is a very topical subject today, there's no question. Had I been giving this lecture five years ago I would have said to you that there are really no good anti-viral treatments, that most of what we have is far too toxic.

Now, since then we've had two, I would call them, wonder-drugs: we've had AZT in the HIV situation, and we've had interferon, which has had its biggest success in hepatitis-B and -C. Both of them have drawbacks, and with the AZT, it is exactly as you've said, the very rapid development of resistance.

Although, I would say to you, that my colleagues, such as Penny and Cooper, & others at Saint Vincents, who are so fantastic in HIV, tell me that the in-vitro resistance doesn't always mean that the drug has stopped working in vivo. There might be some little discordance, and there are people who believe that AZT should be given for longer than the 9 or 12 months, until the disease has developed. But this is a very special virus with quite extraordinary mutation rates, and I think that the fact that AZT works for at least 9 months or so, has given a whole filip to the field of smart antiviral drugs. There are more coming down the track.

Interferon is a different kind of substance. That's not a drug: it's a natural substance of the body. If you want, its the body's own defence against viral infections, apart from the immune system, and it can be mass-produced by recombinant DNA technology, that is a genetic engineering technology, and its been what we call in the trade a 'sleeper'.

Sales of interferon were very disappointing shortly after its introduction, but more uses are being found as doctors learn how to use the drug better (its expensive, of course). The main areas in which it has had greatest

success are certain forms of cancer and overwhelming viral infections. There is progress. We do not yet have the 'penicillin for viruses', something as completely non-toxic and also very broad in its effectiveness as the antibiotics, but the progress is now quite good good.

Further question from Dr Lowenthal: The other side of that is what you might call the reaction to the innoculation or vaccination: I mean, a vaccination takes hold of an agent of the body, and no doubt the system reacts to it, and to some extent it may need another vaccination to cure the first vaccination.

Sir Gustav: Well, look, you're also right there, Dr Lowenthal. There is no medical intervention, even taking an aspirin, one aspirin, which is entirely risk-free. So any medical intervention has a risk-benefit aspect. Take anaesthetics: you know, I receive from the Medical Board each year the report on anaesthetics deaths in Australia. And its not a very small number: it's not like three, you know: there are always numbers of 20, 40 or so anaesthetic deaths per year: the accidents which shouldn't happen but do.

I can tell you that with vaccines slight reactions are very common: by slight reactions I mean the reddening of the injection sites, a sore lump in the groin, a fever. Or even, with the measles, mumps, rubella vaccine, a little bit of a rash, just a few little marks of colour; these are what you might call in the trivial class. The fever may not happen, we're often told now to give the kids some Panadol, because that'll avoid a bit of trouble the next day.

Now you're not really referring to these. There are, occasionally, more serious reactions, and the worst of the reactions has been with the whooping cough component of DPT. In roughly one case in two thousand, the whooping-cough vaccine will cause febrile convulsions. This is not dangerous, but is extremely distressing, as any of you who have had kids or grandkids who have had convulsions will agree.

However, the serious complication of an encephalitis, leading to permanent brain damage, has been intensively investigated in every English-speaking country in the world, most prominently in the United States. A blue ribbon panel has recently published the incidence of serious CNS complications as somewhere between one in 200,000 and zero. In other words, it is so rare, that even this profound investigation could not deny the possibility that the few cases which appeared in the year in the United States were totally due to chance. So the serious complications are vanishingly rare.

There is now an acellular pertussis vaccine which has no whole bacteria in it: it just has material from the bacteria, much purer, totally non-reactogenic, and it works wonderfully. Your grand-kids will be getting this vaccine within a year or two; whether the African villagers will be, is a very different question. That's where I have to be persuasive and optimistic, as the vaccine is much more expensive. But the technical problem is now solved.

With polio, incidence of reversion to virulence of the Sabin vaccine is estimated at somewhere between one in half a million & one in two million. Not negligible, if you happen to be the one in two million; and in the United States there is now a very lively debate as polio transmission has ceased, to ask the question whether the old Salk vaccine, which is killed, and therefore entirely safe, should come back: they're talking about two shots of Salk vaccine followed by two doses of oral Sabin vaccine.

Once again that's a question of cost. The injection is much more expensive, it has to have much more virus in it than the oral (which multiplies itself in the gastro-intestinal tract). So aren't these nice questions? We can afford the luxury of debating it for the one case in two million. I think the African villagers cannot afford the luxury of that debate: they will have to stay with the Sabin vaccine for now.

Dr E.C.Potter: There's a lady living in France, who, if she lives for six weeks or so, will become the oldest person who has ever lived. She was born in 1875: do you think there is something to learn from studying the extreme aging?

Sir Gustav: Oh, look, I think that is a totally fascinating question: I happen genuinely not to be an expert on the question, but it is not only worthy of study, but it is being studied extremely intensively. However, not quite so much in people, but more in mice & rats. For the very simple reason, that a rat and a mouse live for three years, and therefore you can work towards four & a half year-old rats, but you can't do a lot of work for 120 year old women.

There are some fascinating things that are already clear: let me hit you with the clearest, which was surprising: that malnutrition can lead to huge prolongation of life. Huge! So if you feed mice & rats a low-protein diet, and have the mice & rats go through their lives looking like a Belsen concentration camp victim, they'll live longer.

The fact is that puberty is delayed, the

menarche is delayed, and the menopause is delayed, everything is delayed; but so, of course, is mental development. So, I mean, this is a trivial example, because it's a life totally lacking in quality: it's not realistic. But it does show that the life-span, as such, is not absolutely fixed, and there are profound things yet to be learned about ageing.

However, I would put it to you, that the real centre-point of the ageing dilemma is encoded by that very brief statement that I've already made: a fly lives for a few days, a mouse lives three years, a dog lives fourteen, a human lives eighty: then there's standard deviations on either side.
Now, no mouse has ever lived to eighty, no dog has ever lived to forty: dogs might get to twenty-two or something, so there seems to be some program, some program entity which we don't understand at all, that's got to do with the nature of species & speciation, that determines how long that particular biological species will live. What that program may be is is the subject of very intense investigation, with more questions than answers.

Mr G.W.K.Ford: There was this debate about, if you stamp out smallpox, do you or do you not stamp out the final laboratory strains? That must be a general question applying to all these things?

Sir Gustav: I had the great good fortune, in relation to this question, of sitting next to Frank Fenner at a dinner a few weeks ago. Frank Fenner is the doyen of Australia's virologists, who has been multiply honoured for his role in the smallpox eradication campaign, which in large measure was based upon his model work with both myxomatosis and mouse-pox, the ectromelia virus. His belief very strongly is that, once eradication has not only been certified, but has also been documented by experience, you know, that after the certification nothing's happened, that all stocks should be destroyed.

He justifies that on the following basis: should it ever be necessary to re-create the virus, the virus has been completely sequenced, all of its genetic code is known, and should there be some secret encrypted in there, some kind of genetic engineering could re-create it anyway, so that there is no excuse for keeping the actual specimen. Now that is not a universal view, but it the view that the World Health Organisation has adopted, and it is now a question of the Russians signing off. Because I think, from memory, there are three repositories, and these three parties have to agree: I think there's one in Washington, there's one in Moscow, & I think there may be one other one under the control of the WHO.

President: Thank you very much, Sir Gustav. I'll call upon Dr Norbert Kelvin to move the vote of thanks to our speaker:

Dr Norbert Kelvin: Sir Gustav, it gives me great pleasure to propose this vote of thanks. I think that this work just shows how important human endeavour is to making our lives more enjoyable, more fulfilled, longer. I think that we are truly blessed in this country to have a man of Sir Gustav's stature working on these kinds of ventures. I must say that, as a chemical engineer, I'm fascinated by the prospect of chemical engineers around the world looking at better ways of delivering these drugs, not just manufacturing them, but delivering them, and I think that there is an enormous opportunity for engineers & chemists, and scientists generally, to improve the methods of delivery, as he has shown: this is a quite unique opportunity. Well, without any futher ado, I'd like you all to join me in giving our usual expression of thanks for your wonderful talk.

(applause)

Closure: the President invited Sir Gustav, and visitors, to sign the Society's Visitors' Book, which was commenced in 1876: a year after the French lady, mentioned by Dr Potter, was born!

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Inorganic Chemistry: Frontiers and Future

I. G. DANCE

Liversidge Lecture 1994

Abstract

Inorganic chemistry – the chemistry of all elements – has turned up some real surprises in the last few years. Even elemental carbon is undergoing a revolution, literally. Molecules which are simply binary combinations of the elements, such as M_xS_y and M_xC_y, have been discovered. These are molecular fragments of compounds otherwise known only as non-molecular solids, and are totally unexpected and unpredictable: their structures are being explored by computational methods. The multiple "non-bonded" interactions between inorganic molecules in crystals are being recognised and understood, and can be deployed in crystal engineering. Highly evolved molecular biology reveals tantalising chemical possibilities beyond current laboratory capabilities, such as the mild reduction of the most recalcitrant molecule in chemistry, N_2, by the enzyme nitrogenase. Insight into the mechanism of this enzyme comes from investigations of the clusters M_xC_y.

Introduction

Professor Liversidge's instructions required that ".. the lectures shall be such as will primarily encourage research and stimulate the lecturer and the public to think and acquire new knowledge by research ..". I trust that by examining some of the current frontiers of inorganic chemistry, and by looking forward, this account will meet his expectations.

Of the many frontiers in inorganic chemistry, I will focus here on several that I see as contemporary and expanding. My approach is mainly inductive, and, consistent with the terms of the Liversidge endowment, seeks more to point to significant directions of research and less to review current knowledge.

What is inorganic chemistry, and where are its frontiers? The name "inorganic chemistry" reveals only what this science isn't, and is unsuitable, and anachronistic. However, I don't expect an immanent and positive renaming of this field of science, particularly since it took so long even to effect a logical renumbering of the periodic table. The old name of the Inorganic Division of the Royal Australian Chemical Institute, namely "Coordination and Metal-organic Chemistry", is more positively descriptive.

Inorganic chemistry is the chemistry of compounds of all of the elements, involving the fundamental chemical activities and attributes of (1) **synthesis**, (2) **structure** (geometric and electronic) and architecture for molecules and assemblies, and (3) **reactions and reactivity**. There are close and important connections with the fields of catalysis, and with materials and the materials sciences, and with the biological sciences. Like non-inorganic chemistry, it is supported by theory, by the innumerable spectroscopies, and by analysis.

Structural Molecularity

One essential characteristic of compounds over the periodic table is the molecularity of their architectures and geometrical structures. Structural molecularity refers to the existence, or not, of the discrete groups of atoms which are termed molecules because they are surrounded by non-bonded boundaries. Actually, the boundaries which surround and define molecules are weakly bonding rather than non-bonding, but the significant fact is that the intermolecular attractive energies are an order of magnitude less than intramolecular bond energies. The significance of structural molecularity in inorganic chemistry can be illustrated with one of the frontiers, namely the chemistry of the element carbon. For a very long time our knowledge has been restricted to two allotropes of carbon, diamond and graphite. Both of these are non-molecular: diamond is three dimensionally non-molecular because there are infinite extensions of strong bonds in three dimensions, while graphite is two-dimensionally non-molecular. But then came C_{60}, which is totally molecular and remarkably symmetrical, as shown in Figure 1. The bonds around the 12 pentagons and 20 hexagons in C_{60} are arranged exactly as the seams in a soccer ball. The molecular allotropes of carbon are named "fullerenes", from the analogous architecture of the geodesic domes of Buckminster-Fuller. And not only is there one molecular allotrope of carbon, but there are many fullerenes C_n, some with $n < 60$ but most with $n > 60$. And there are geometrical isomers of individual fullerenes C_n. Further, elemental carbon which is one-dimensionally non-molecular is known in the carbon nanotubes, which are like concentric rolls of graphite. Part of a single nanotube is illustrated in Figure 2. In a little over a decade the inorganic chemistry of a common and long-known element, carbon, has undergone a surprising revolution which is spawning a plethora of compounds with intriguing properties.

The Domains of Inorganic Molecules

This frontier of inorganic chemistry, namely the occurrence of molecules and of molecular structure for compounds previously known only in non-molecular form, is occurring with many other fundamental inorganic compounds, as I will explain below. In order to develop this frontier and others, I

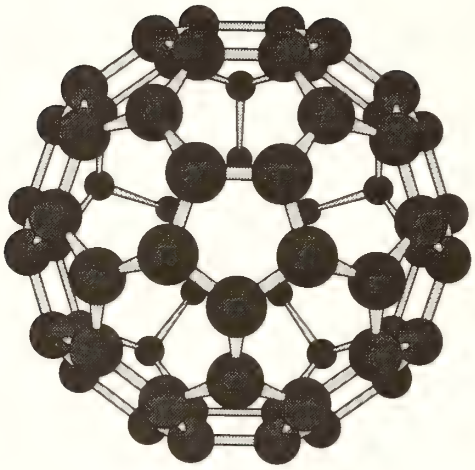


Figure 1 A molecular allotrope of carbon, C_{60}.

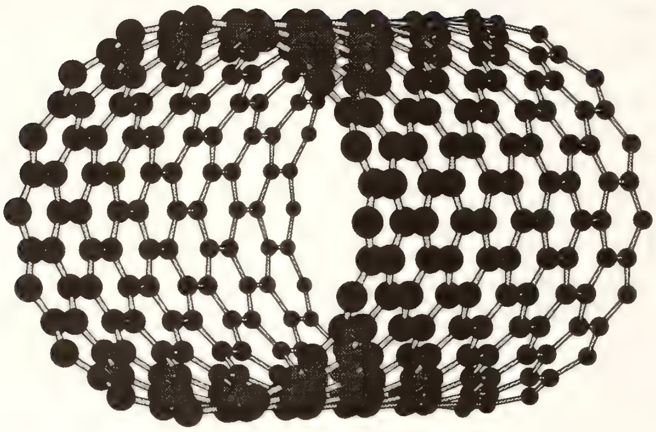


Figure 2 A short length of carbon nanotube.

will define a conceptual framework for the components of molecular metallocompounds. Figure 3 shows the molecular structures of the cluster compound $[S_4Cd_{10}(SPh)_{16}]^{4-}$ which we have investigated. In this Figure the atoms are shaded according to location in the molecule.

These molecules can be viewed as having three domains, the domain $\mathbb{M}$ of the metal atom or atoms usually near the centre, surrounded by the domain of the ligand donor atoms $\mathbb{D}$ bonded directly to the metals, which is then surrounded by the ligand framework $\mathbb{L}$ often composed of carbon and hydrogen. These domains are shown diagrammatically in Figure 4, with the same shading as Figure 3. Tens of thousands of other metallocompounds can be viewed the same way: they vary in size and shape but this analysis of molecular architecture is widely sustainable, and is implicit in most of the literature.

Two of the frontiers of inorganic chemistry involve modifications of this view: I am going to subtract and add domains. One of the frontiers involves molecules in which the ligand framework $\mathbb{L}$ no longer exists. The molecules contain only the $\mathbb{M}$ and $\mathbb{D}$ domains, and they are commonly encountered as binary compounds in **gas phase inorganic chemistry**. The metal and donor atoms, often quite intimately involved, are effectively in vacuum.

The expanded view of metallomolecules focuses on their periphery, domain $\mathbb{P}$, and on its interaction with the environment of the molecule, domain $\mathbb{E}$ (see Figure 5). In the condensed phases, where most chemistry occurs, every molecule has an environment, and interacts with that environment through weak interactions. This is the frontier of **supramolecular inorganic chemistry**.[Dance, 1995]

Supramolecular chemistry is the chemistry of non-bonds, or "chemistry beyond the molecule", or interactions across the boundaries of molecules.[Lehn, 1990] Supramolecular chemistry is precisely the interaction between the periphery of a molecule and its environment. Supramolecular chemistry is distinct from supermolecular chemistry, which deals with big molecules. The importance and significance of interactions across molecular boundaries has of course been known for a long time in molecular biology, and its significance is well recognised in that context. But only in recent years has that knowledge been developed for non-biological molecules, and for metallomolecules and inorganic compounds this is a frontier yet to be explored.

There are two other important themes that I will describe. One is the relationship between molecular biology and metallochemistry, and the other is the contribution of computational methods to the development of metallo-chemistry. Thus the four principal frontiers of inorganic

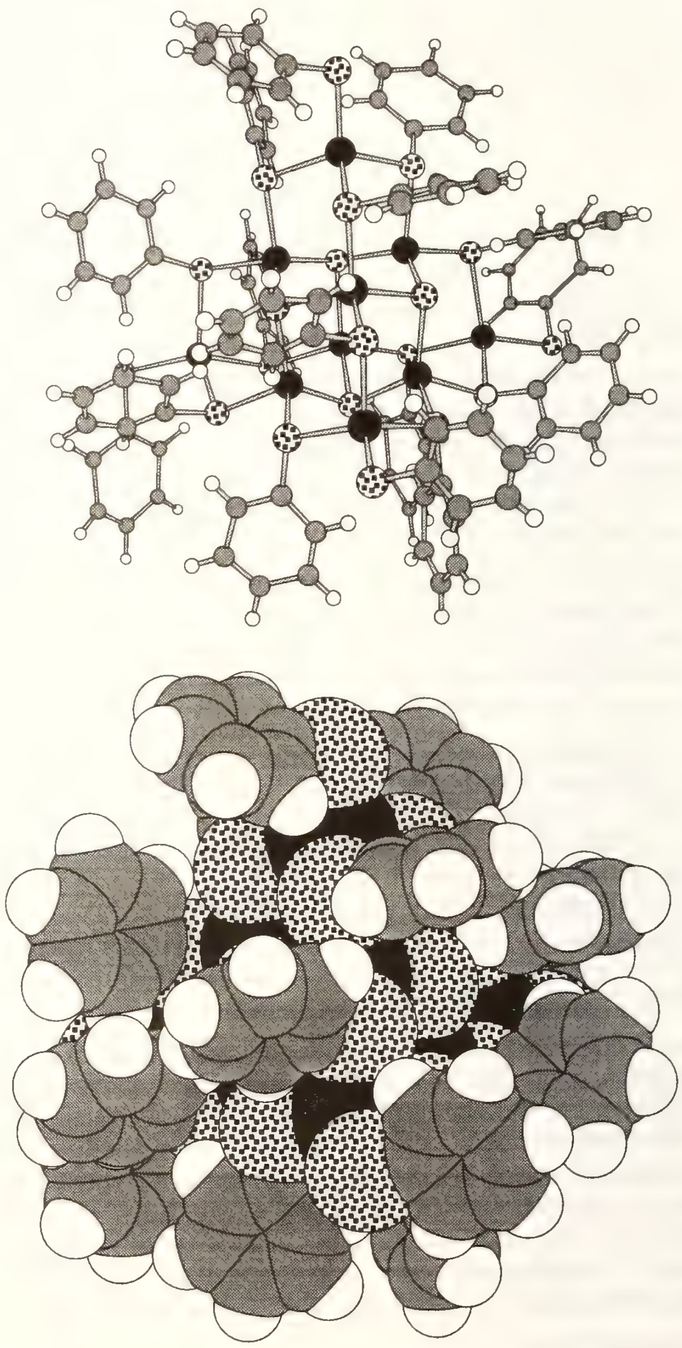


Figure 3 Skeletal and space-filling pictures of $[S_4Cd_{10}(SPh)_{16}]^{4-}$, representing the domains. The metal atoms are dark, the donor atoms bonded to the metal are speckled, and the outer atoms are grey (carbon) or white (hydrogen).

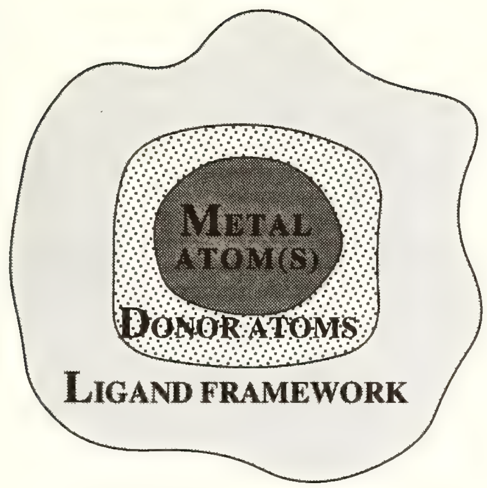


Figure 4 The domains of a metallocompound, 𝕄, 𝔻, and 𝕃.

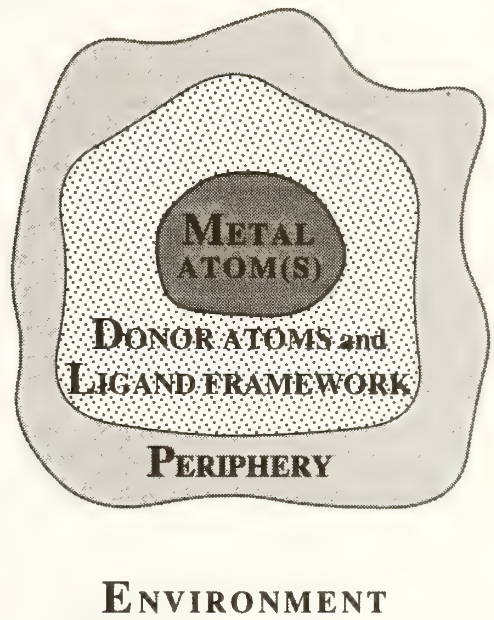


Figure 5 The domains of a metallocompound in a condensed phase environment.

chemistry to be championed here are:

- Supramolecular metallochemistry — the total view
- Gas-phase metallochemistry — the fundamental and pristine state, indicating possibilities and opportunities
- The contributions of computational methods — which are now powerful
- The knowledge-base of molecular biology — and its recognition and use in inorganic chemistry

I will first develop and illustrate some of the concepts of supramolecularity for metal containing compounds, concentrating on the interface of the molecular periphery and the environment. Then I will describe some of our gas-phase inorganic chemistry, the cut-down and pristine view of inorganic chemistry, which reveals the fundamentals and the possibilities and opportunities. This will involve a brief description of the power of contemporary computational methods for these compounds, and finally I will look at naturally occurring systems, in particular the amazing enzyme nitrogenase.

Supramolecular metallochemistry

Why is supramolecular chemistry so important? Most of the processes of life depend on molecular recognition, and on the concerted and synergistic actions of molecular assemblies. Processes such as the pumping of nutrient chemicals and waste chemicals through cell walls, the conversion of solar energy into chemical energy, the catalysis of reactions under remarkably mild conditions, and the operation of the amazing molecular computer called the brain, all depend on supramolecular chemistry. Nature is the expert supramolecular chemist, and nature, that is evolved molecular biology, uses metals and inorganic materials. Evolved molecular biology has developed supramolecular chemistry to a sophistication far greater than that of any laboratory chemist. Evolved molecular biology reveals amazing possibilities for chemistry, and thereby presents the challenge to understand and possibly deploy these possibilities.

But there is no need to be a molecular biologist to be involved with supramolecular chemistry. As chemists we practice supramolecular chemistry every time we crystallise a molecular compound. The formation of crystals is one of the supreme supramolecular events, and every structure of a crystal is the consequence of innumerable non-bonded interactions.

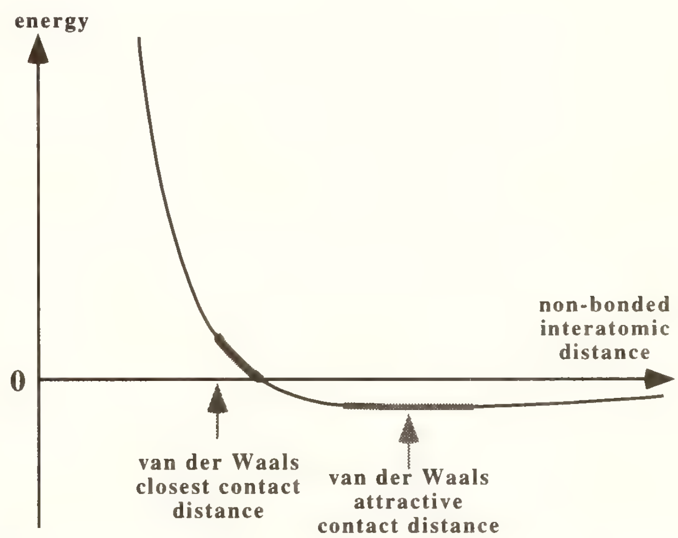


Figure 6 The repulsive and attractive interaction regimes between "non-bonded" atoms.

What are the characteristics and magnitudes of the "non-bonding" interactions? There are the van der Waals repulsive interactions at short distances, and the van der Waals attractions at longer distances, according to the curve in Figure 6. Note that the conventional van der Waals separations and the radii derived from them refer to the closest possible approach, which is slightly repulsive. The attractive interactions, responsible for the condensed phases, are at longer distances, and there is another set of van der Waals radii characterising these attractive interactions for the elements, just as there is a set of values for the magnitudes of the attractive energies at the shallow minima. Van der Waals interactions following curves of this type are described analytically in computer programs for supramolecular chemistry.

There is another interaction, the coulombic forces between regions of excess or deficient electron density in molecules. This is expressed in terms of partial charges on atoms. There are two important attributes of the coulombic interaction, namely its magnitude, and its extent. For metallocompounds the partial charges on atoms can be appreciable, up to about ±1 electrons, and as a consequence the coulombic contributions to

the total energies are often substantially larger than the van der Waals energies.

It is important to recognise that there is an immense amount of data on supramolecular chemistry of metallocompounds available in the Cambridge Crystallographic Database (CSD). Just as crystallisation is common, so determination of crystal structure is very largely a routine operation, frequently practised, and the journals are full of pictures of molecular structure obtained by diffraction analysis of crystal structure. In the 1993 version of the Database there are 115,000 entries, of which 45,000 contain transition metals. The supramolecular information here for metallocompounds is immense, and has been largely ignored.

I will expound here on one aspect, which I call the **phenyl factor**. In the CSD there are 4300 transition metal compounds containing at least one triphenylphosphine ligand. Here the donor domain is phosphorus, and the periphery of each ligand brings three phenyl groups (Ph). In the CSD there are 1150 crystals of anionic compounds using Ph_4P^+ or Ph_4As^+ as the cation. Each of these cations is fully coated with phenyl groups.

Phenyl and related aryl groups in domain $\mathbb{P}$ have specific supramolecular interactions. These are responsible for the characteristic herringbone crystal structure of benzene and its abnormally high melting point. The two interaction motifs for benzene molecules and phenyl groups are the **edge to face** and **offset face to face** conformations. These geometries are determined by coulombic attractions between the partial positive charges on H atoms and the negative π-electron density of the aromatic. The net attractive energy for a pair of phenyl groups is calculated to be almost 10 kJ per mole.

This is known (albeit subconsciously) to many synthetic chemists, who know that phenylated molecules often have lower solubility and form better crystals. It is also the reason why there are so many compounds with Ph_3P ligands, and so many salts with Ph_4P^+ in the Cambridge database: these are the compounds that are easier to isolate and easier to obtain as good crystals, for reason of the phenyl factor. It is also the reason why many metal complexes with extensive heterocyclic ligands have low solubility, and why the trick to increase solubility is to introduce alkyl substituents which are impediments to both of the favourable non-bonded conformations. There are many other ligand systems with these effects: the benzenethiolate ligand gives compounds more easily crystallised than other thiols, and the same applied to phenoxides. Supramolecular chemistry is behind much of the folklore of laboratories engaged in synthetic coordination chemistry.

There is a caveat. The interpretation of crystal structure data to provide information on molecular structure can be invalid if the molecule is conformationally fluxional, because the total energy of the interactions between the molecule and its environment, particularly where phenyl groups are involved, can be larger than the intramolecular conformational energies. Details of molecular stereochemistry could be influenced by the environment in the crystal. Much of the discussion of fine details of molecular structure deriving from crystal structure data is probably unwarranted: the high precision of the crystal structure results can be deluding, because it is tempered by the low accuracy with respect to the structure of the molecule in solution.

The phenyl factor appears in a variety of structures. Some years ago we synthesised and determined the crystal structures of some compounds $Cd(S\text{-}Aryl)_2$, which have complex polycyclic and non-molecular structures.[Dance, Garbutt, Craig and Scudder, 1987; Dance, Garbutt and Bailey, 1990; Dance, Garbutt and Scudder, 1990] For example, the cadmium compound with 2-methylbenzenethiolate when crystallised from N,N-dimethylformamide (DMF) has the formula $Cd_7(SC_6H_4\text{-}2\text{-}Me)_{14}(DMF)_2$.[Dance, Garbutt and Scudder, 1990.] In order to simplify and interpret this structure, we published diagrams which had the phenyl groups removed, to reveal the chains and cycles of Cd and S atoms. However, this is a crystal structure dominated by the phenyl factor. In fact the crystal is composed mainly of aryl groups which arrange themselves in face-to-face and edge-to-face conformations: the Cd-S sequences threading through relatively small spaces, and the DMF molecules are included to fill space, with their coordination to Cd being secondary.

Examples of the phenyl factor occur throughout the crystal chemistry of anionic metal polysulfide compounds, frequently crystallised with Ph_4P^+ cations. An example is $(Ph_4P^+)_4[In_2(S_4)_2(S_6)_2S_7]^{4-}$, [Dhingra and Kanatzidis, 1993] in which the cations construct elaborate networks with multiple attractive phenyl-phenyl interactions. Figure 7 shows this layer of attractively interacting cations in this crystalline compound.

We have recognised a supramolecular motif which occurs frequently in crystals of this type.[Dance and Scudder, 1995] The motif involves two Ph_4P^+ cations embracing through three phenyl groups each, such that hydrogen atoms on each Ph group are attracted to C atoms of the next ring on the other cation, with the interactions arranged fairly symmetrically around the array of six Ph groups involved in the embrace.

In short, the cations are calling the supramolecular tune in these compounds. These features provide opportunities for crystal design and engineering. There is a gold mine for research here. With understanding of crystal structures (as distinct from molecular structures) it will be possible to design and fabricate materials using these supramolecular principles. There is a large volume of design data available in the Cambridge crystallographic database.

Inorganic gas phase chemistry.

In the following I strip away all of the environment, and all of domains $\mathbb{L}$ and $\mathbb{P}$, and look at molecular systems which contain only metals atoms and donor atoms. In many cases these will be binary compounds, M_xE_y (E = any element),

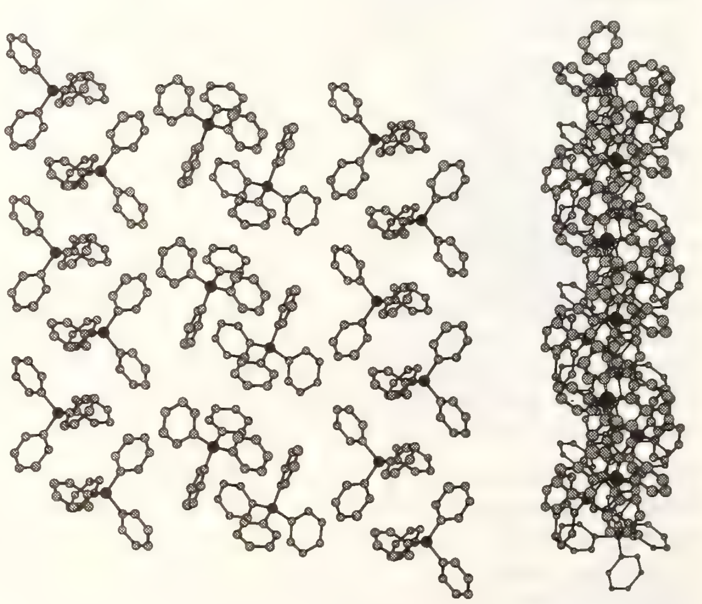


Figure 7 The layer of attractively interacting Ph_4P^+ cations in crystalline $(Ph_4P^+)_4[In_2S_{27}]^{4-}$: (a) front view; (b) side view.

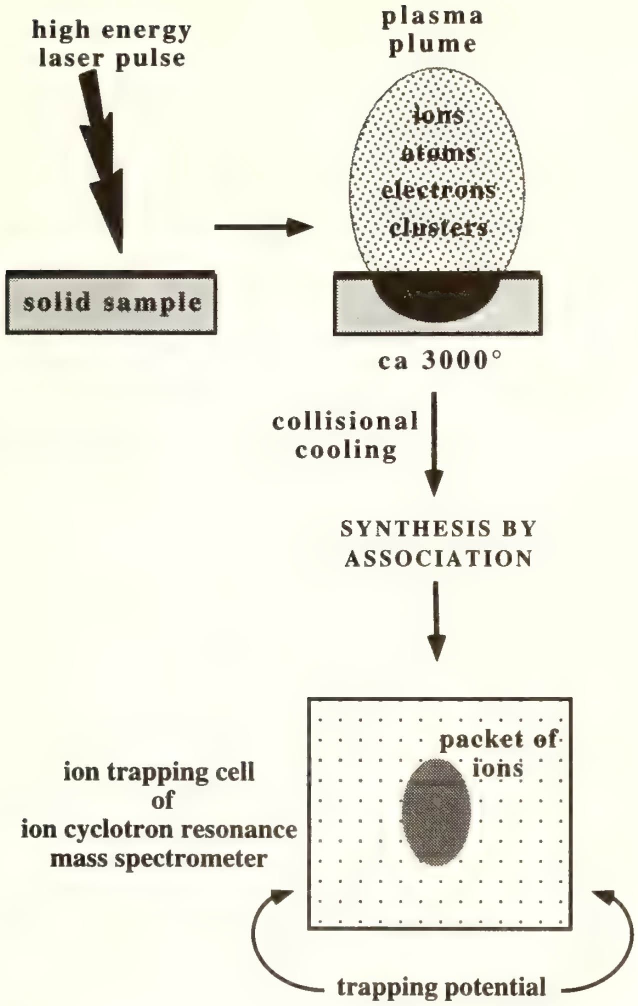


Figure 8 Simplified representation of the gas phase synthesis experiments using laser ablation for generation of precursors, and product containment and monitoring in an ion trap mass spectrometer.

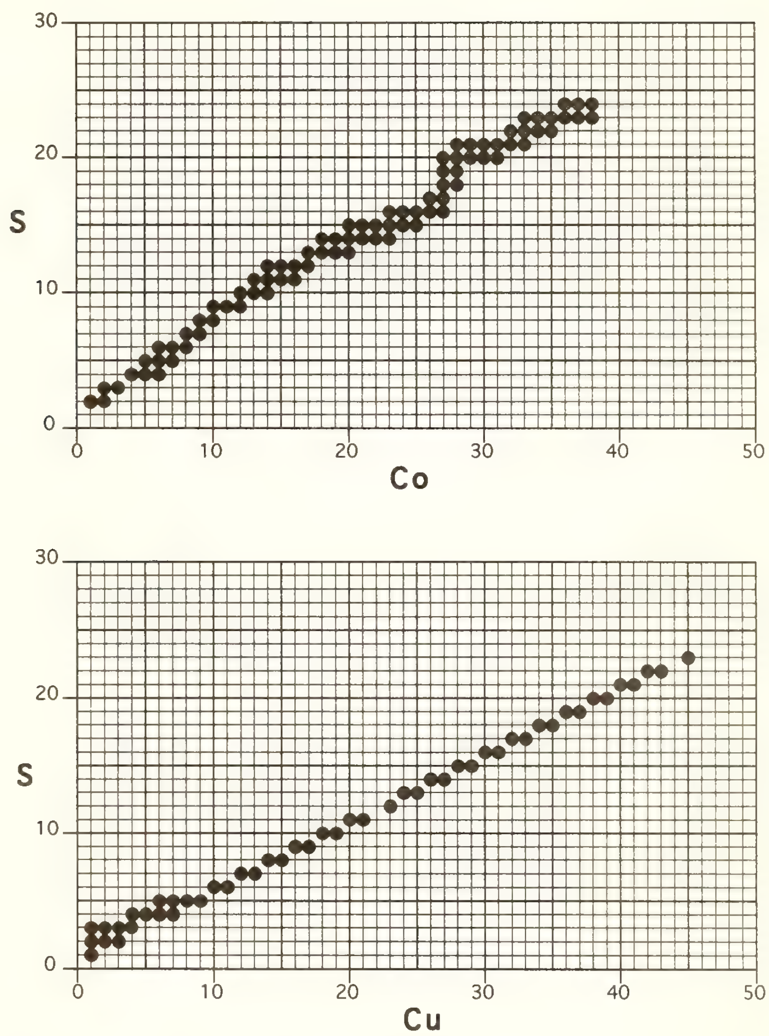


Figure 9 Maps of the compositions of the ions $[Co_xS_y]^-$ generated by laser ablation of CoS, and of the $[Cu_xS_y]^-$ ions formed by laser ablation of various copper solid solids.

previously known only with non-molecular structure as metal oxides, sulfides, nitrides, phosphides, and carbides.

Our research here involves synthesis in the gas phase, through ablation of a solid using a high energy laser pulse, creating atoms, ions and molecular fragments in the plasma plume above the hot surface of the solid (see Figure 8). As these cool they reassemble to form molecules and clusters. These are contained in the ion trap of a Fourier transform ion cyclotron resonance (FTICR) mass spectrometer, where they can be separated, held, monitored, and reacted with other gaseous reagents. It is important to recognise that this is unlike conventional mass spectrometry, because it does not reveal molecules present in the precursor solid but rather allows synthesis by assembly of atoms, ions, and small fragments liberated from the precursor. Further, the time scale for experiments in the ion trap ranges up to 100 seconds, which is very many orders of magnitude larger than in ion beam experiments.

I will present a representative selection of our results. When CoS is subject to laser ablation the mass spectrum of negative ions contains 83 peaks, each of which is a new *molecule* containing only Co and S.[El Nakat, Fisher, Dance and Willett, 1993] Prior to this cobalt sulfide was known only as a non-molecular solid, and our result reveals an unexpected vista of cobalt sulfide molecular chemistry. Figure 9 contains a map of the compositions of these new ions $[Co_xS_y]^-$ obtained by laser ablation of a sample of CoS, and also a map of $[Cu_xS_y]^-$ from a similar experiment involving copper.

Similar results are obtained with other metal sulfides.[Dance and Fisher, 1994] Figure 10 maps the compositions of the molecular sulfides formed by iron and nickel. These charts give the composition rules for molecules of compounds previously seen only as non-molecular solids, and as minerals. We have no predictive methodology for such compounds, and now seek to determine the new chemical principles that are contained in their compositions and structures. This chemistry is unexpected and unprecedented, and yet reveals the fundamentals of inorganic binary compounds. This frontier is a binary analog of the fullerene frontier for elemental carbon.

It is possible to separate these ions in the gas phase, and thereby to keep just one composition in the ion trap, and then to study its reactions and reactivity. There are as yet no direct data about structure, and experimental access to structural information is rather difficult with the very low concentrations in the gas phase. Our experiments occur at pressures of less than 10^{-8} mbar.

In this situation, where intriguing new molecules are glimpsed but cannot be easily subjected to spectroscopic characterisation, important insight can be provided by theory and computational methods. In these compounds where the bonds are likely to be unusual, force-field methods which require pre-definition of bonds are quite unsuitable. The appropriate technique is quantum theoretical calculation of the electronic structures of these compounds, coupled with geometry optimisation by minimisation of the electronic energy. There are various levels of quantum theory which have been applied to transition metal compounds, but the density functional methodology which I will describe and have used extensively is very promising for inorganic chemistry, and for big molecules with big atoms.

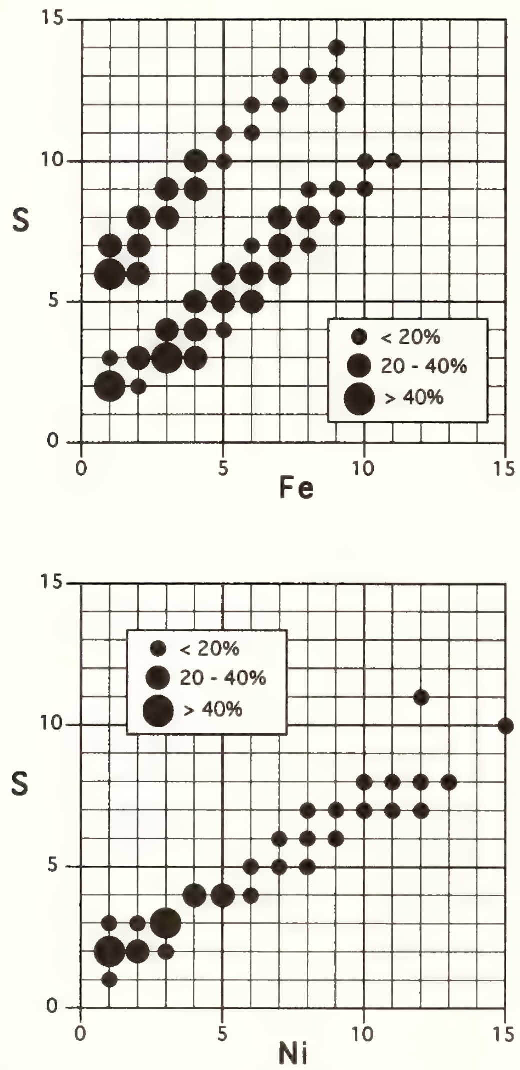


Figure 10 Maps of the observed compositions of the ions $[M_xS_y]^-$ formed by laser ablation of the sulfides of iron and nickel.

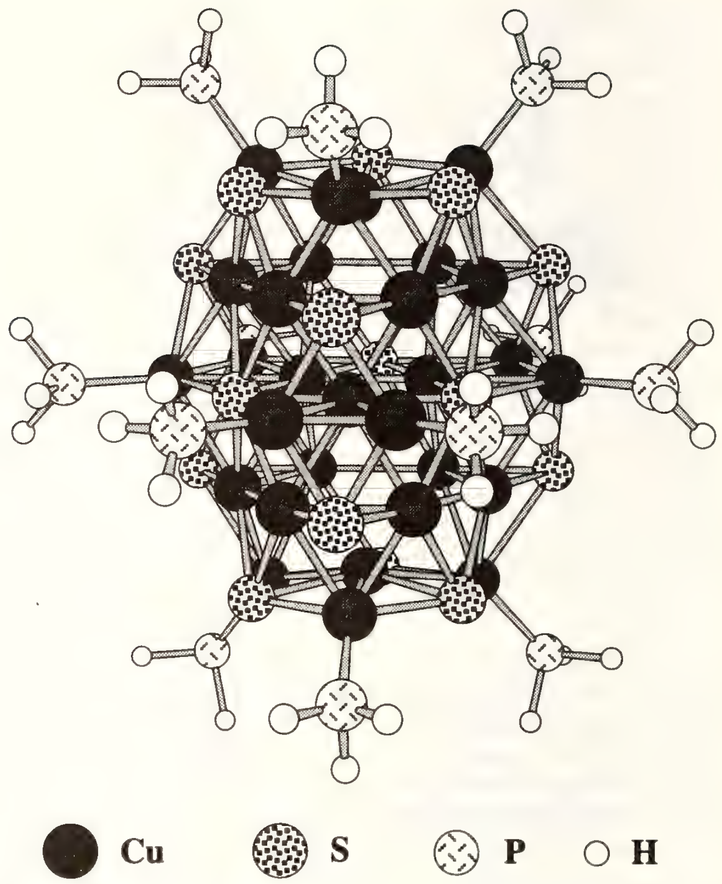


Figure 11 The calculated structure of $Cu_{29}Se_{15}(PH_3)_{12}$, which is virtually identical with the measured structure of $Cu_{29}Se_{15}(PPr^i{}_3)_{12}$.

Density functional theory

Density functional theory, which has been used in solid state physics for decades, is quantum theory in which the conventional Schrodinger equation is re-expressed (by the Hohenberg-Kohn theorem) in terms of the electron density. The difficulty in quantum theory is evaluation of the two-electron interaction energies for complex systems: these two-electron interactions are the exchange and the correlation energies. In density functional theory these energies are derived from their expressions for an electron gas. In effect this is *ab initio* quantum theory, in which there are no empirical parameters, but there are variations in the "functionals" which describe the exchange and correlation energies. The two important advantages of density functional methods (relative to conventional Hartree-Fock methods) are the suitability for inorganic molecules where exchange and correlation energies are more significant, and computational expediency which allows investigation of larger molecules with accessible computing resources.

The methods I use are embodied in the computer program DMol, with geometry optimisation by energy minimisation. The accuracy and power of this computational chemistry are demonstrated by results for the large metal selenide cluster $Cu_{29}Se_{15}(PPr^i{}_3)_{12}$, optimised as $Cu_{29}Se_{15}(PH_3)_{12}$, pictured in Figure 11. The calculated bond distances are generally within 0.05Å of those measured for $Cu_{29}Se_{15}(PPr^i{}_3)_{12}$. This provides confidence in the application of density functional methodologies to the newly observed inorganic clusters with unknown structures. I see a very valuable future for density functional theory in inorganic chemistry.

The density functional calculations minimise the energy and thereby optimise the geometry for a postulated geometrical structure. They enable the mapping of the geometry–energy hypersurfaces of the newly discovered inorganic molecules, and elucidation of the new structural and bonding principles. Using this method I have been able to explore and optimise the structures of many of the metal sulfide clusters. These results, and the structural principles they reveal, are too voluminous to report here, but I will provide some results for a different new frontier in gas phase inorganic chemistry, that of metal carbon clusters.

In addition to the fullerenes, there are metallofullerenes in which metal atoms reside inside or outside the carbon cages, and there are metal-filled carbon nanotubes. A related but different class of unprecedented binary metal-carbon compounds are the **metallocarbohedrenes**, which are clusters of approximately equal numbers of metal and carbon atoms. Metallocarbohedrenes are generated in the gas phase by reaction of metal clusters with hydrocarbons.

The first metallocarbohedrene to be detected, in 1992, was Ti_8C_{12}. The original proposal for its structure was the cube of Ti with C_2 groups parallel to the edges, as shown in Figure 12 (a). However, I was able to show by density functional calculations that the alternative structure in Figure 12 (b) is very much more stable, by more than 1000 kJ mol^{-1}. [Dance, 1992] This structure has four inner Ti atoms and four outer Ti atoms, which form slightly folded diamonds on the surface, and the C_2 groups are cradled in the diamonds, along the long diagonals. All other theoretical investigations have now confirmed the much greater stability of this alternative structure, and the C_2 group diagonal to a diamond shaped array of metal atoms is a prominent geometrical feature of other stable metallocarbohedrenes.

An interesting sequence of copper carbohedrenes has been reported recently, with many belonging to the general series $[Cu_{2n+1}C_{2n}]^+$. Using density functional calculations I have defined the structural principles for them.[Dance, 1993a] In Figure 13 are shown the optimised structures for $[Cu_{13}C_{12}]^+$ and for $[Cu_{25}C_{24}]^+$.[Dance, 1993b] Again a key structural feature is the occurrence of C_2 groups diagonal to Cu_4 quadrilaterals.

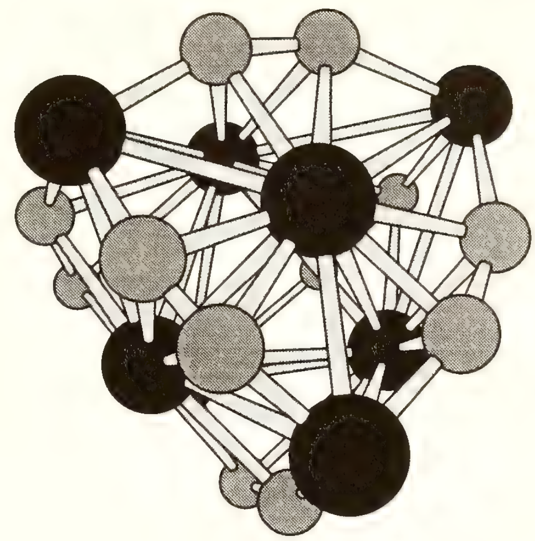
The C_2 group which appears to be a fundamental feature of the metallocarbohedrenes is formally $C_2{}^{2-}$, or acetylide, which is isostructural with cyanide, CN^-. Therefore we have commenced investigations of gas phase metal cyanide chemistry. While there is an immense literature on metal cyanides and their applications in solution and in solids, prior to our research only one paper mentioned metal cyanides in the gas phase.

The laser ablation of copper cyanide or silver cyanide generates series of positive ions with the composition $[M_x(CN)_{x-1}]^+$ and negative ions $[M_x(CN)_{x+1}]^-$.[Dance, Dean and Fisher, 1994.] These retain the formal M^{+I} oxidation state. Again the question arises, what are there structures? The structural principles which evolve from the density functional investigations of various postulates are very different from those of the copper carbohedrenes. The most stable structures are those in which cyanide forms a linear bridge between metal atoms, which are themselves two-coordinate, forming long linear molecules, as shown in Figure 14. These are unique molecules in chemistry: the $[Cu_5(CN)_6]^-$ ion is more than 30Å long, and yet only one atom thick. In addition to the image of an abacus invoked in Figure 14, these molecules suggest spear-like concepts. This research on the fundamentals of copper and silver cyanide molecules in the gas phase reveals possibilities for new structures and properties in metal cyanide chemistry. There are no analogs of these linear structures amongst crystalline metal cyanides, and the challenge is now how to stabilise such molecules in crystals.

The gas phase chemistry of zinc and cadmium cyanides is equally intriguing.[Dance, Dean and Fisher, 1995] The anions observed after laser ablation belong to a general series $[M_x(CN)_{2x+1}]^-$. The structure type which is supported by computational investigations, using both density functional and force-field methods, is a helix of the type shown in Figure 15. Here each metal atom is three-coordinate, approximately planar, with one terminal cyanide ligand and connected by two linear cyanide bridges to adjacent metal atoms in the helix. The helix is maintained by coulombic attractions between bridging cyanide ligands and the contiguous metal atoms in the preceding and succeeding turns of the helix. The terminal cyanide ligands are not radial to the axis of the helix, but bent slightly in order to increase the coulombic energy with contiguous metal atoms. Stability is also maintained if the helix contains 6.7 metal atoms per turn rather than the 5.7 metal atoms per turn shown in Figure 15.

The metal cyanide helices in Figure 15, and the metal cyanide spears of Figure 14, have been assembled in the gas phase from M and CN fragments. These new architectures are not present in the precursor solids, and now the challenge is synthesis of the newly revealed structures in condensed phases.

Finally, having described research on new polymetal compounds containing the $C_2{}^{2-}$ and CN^- ligands, I will turn to another diatomic ligand which is isoelectronic with them, namely N_2. The special interest in N_2 and metal clusters occurs for the enzyme **nitrogenase**, which effects the biological reduction of N_2. This is most intriguing chemistry. The N_2 molecule is one of the most recalcitrant in chemistry,



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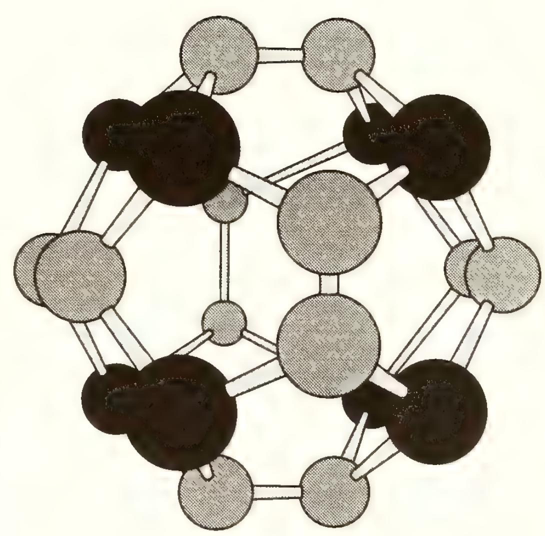
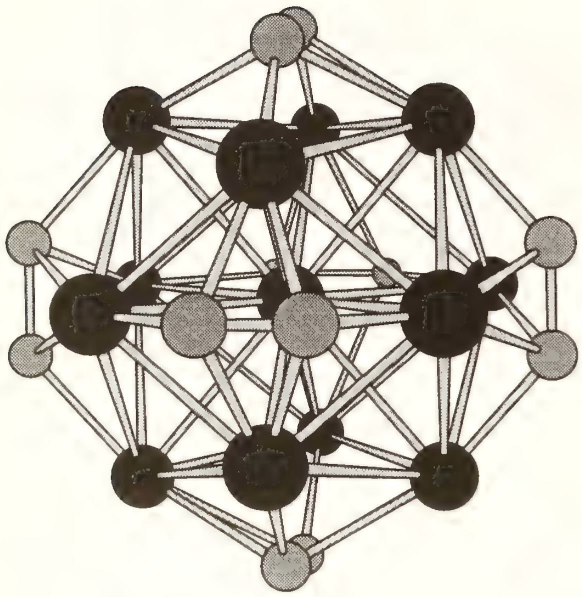


a

Figure 12 (a) The original proposal for the structure of the metallocarbohedrene Ti_8C_{12}. (b) The most stable structure for Ti_8C_{12}, as revealed by density functional calculations.

with a very strong triple bond. Industrial processes for the hydrogenation of N_2 (developed by Haber during the first world war and now used principally for production of fertilisers), involve pressures of 100 – 1000 atm, temperatures of 400 – 500°C, iron catalysts, and cause only partial conversion. Meanwhile the enzyme nitrogenase, present in bacteria symbiotic with plants, catalyses the reduction of N_2 to the amines of life at a N_2 pressure of 0.8 atm and ambient temperature. It is established that the active site where N_2 is bound and reduced is a metal sulfide cluster, containing iron and (normally) molybdenum. The question which tantalises inorganic (and other) chemists is simply: How does it work? What is the mechanism?

In 1993 the structure of the main proteins of the enzyme, and of the active site, were revealed by Xray diffraction of crystals.[Kim and Rees, 1992; Chan, Kim and Rees, 1993; Bolin, Campobasso, Muchmore, Mortenson and Morgan, 1993] The essential features of the Fe_7MoS_9 cluster at the active site are shown in Figure 16, together with the significant protein environment and the two connections between the cluster and the protein. While this structural



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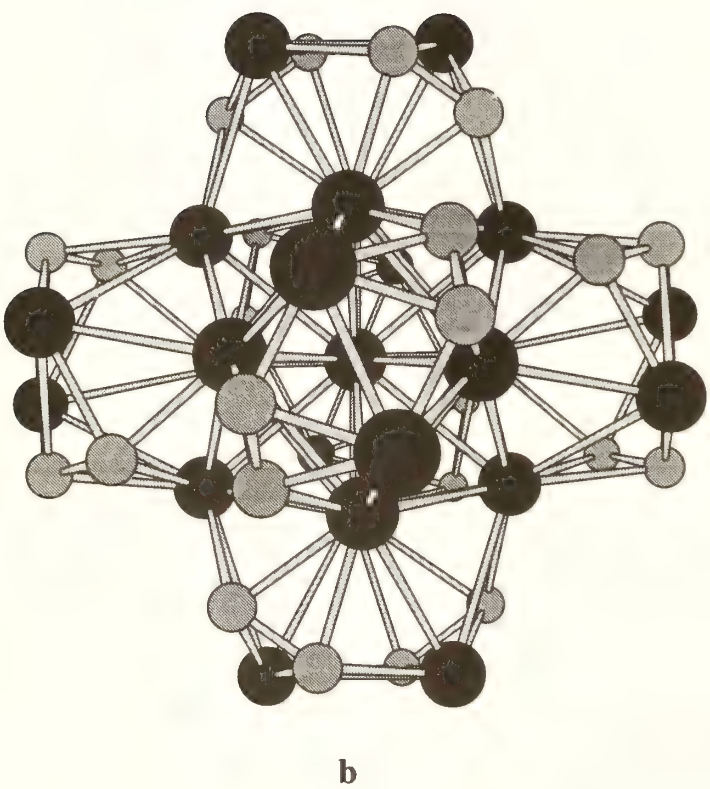

b

Figure 13 The optimised structures of the copper carbohedrenes (a) $[Cu_{13}C_{12}]^+$, (b) $[Cu_{25}C_{24}]^+$.

revelation was a major breakthrough, the new information referred to the inactive enzyme, and the question of the site of binding of N_2 and the question of mechanism remained unanswered.

In this context my investigations of the binding of C_2^{2-} to the faces of metal clusters allowed me insight into the possibilities for nitrogenase.[Dance, 1994] The six iron atoms at the centre of the Fe_7MoS_9 cluster constitute an approximate trigonal prism, with three quadrilateral faces similar to those which bind C_2 in the metallocarbohedrenes. There are iron carbohedrenes with structures similar to the other metallocarbohedrenes mentioned above. Examination of the protein surrounds revealed that one of these faces was very

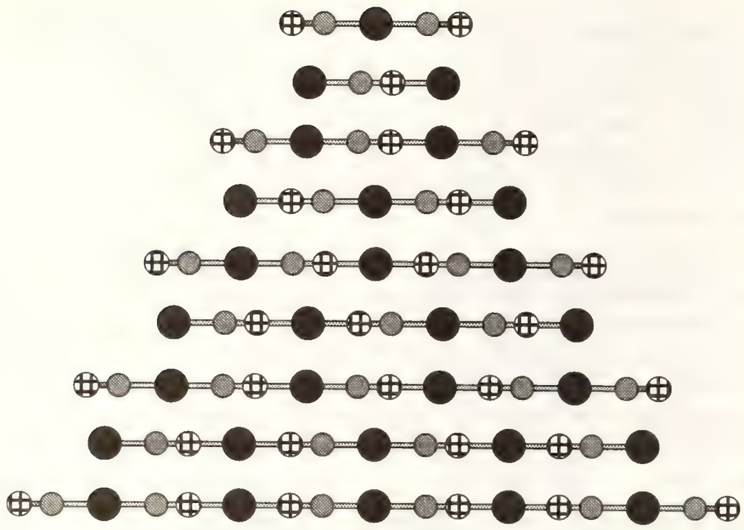

Figure 14 The structures of the gaseous metal cyanide ions $[Cu_x(CN)_{x-1}]^+$ and $[Cu_x(CN)_{x+1}]^-$. Cu atoms are dark, C atoms grey, N atoms hatched.

suitable for binding of N_2. Further, it was known from the metallocarbohedrene investigations that the most bonding configuration for C_2 was along the long diagonal of an M_4 rhombus, while location of C_2 parallel to an edge of rectangular M_4 was antibonding. This factor connected with the fact that the Fe_7MoS_9 cluster was connected to the protein only at its ends, with the Mo end anchored while rotation about the Fe-cysteine bond would be unrestricted. If the top section of the cluster and the Fe_6 trigonal prism rotated slightly relative to the bottom section, the Fe_4 face at which N_2 is postulated to bind could change between a rectangle and rhombus, and provide the bonding and antibonding configurations for N_2.

These hypotheses were evaluated by density functional calculations of the ligated Fe_7MoS_9 core, with bound N_2, and small twists about the long axis. These calculations support the hypothesis that twisting of the cluster core will be a factor in the binding of N_2 and then in the weakening of the triple bond of bound N_2.

This model was developed further, in terms of the supply of H^+ to the N_2 during the course of reduction. There are two sulfide ions which flank the binding site and doubly bridge pairs of Fe atoms on the vertical edges of the Fe_6 trigonal prism. Calculations show that addition of electrons to the cluster causes greatest variation of partial atom charge at these flanking S atoms, which become more basic on reduction. Further, these sulfide ions are able to participate in hydrogen bonds to residues behind the binding face. Thus there is a straightforward hypothesis which involves these two S atoms becoming more basic during reduction, and transferring to the coordinated N_2 a pair of H^+ introduced via hydrogen bonds. This feature of the mechanism is also supported by density functional calculations.

After reduction, product ammonia leaves the active site. The binding site and mechanism which I advance explains this stage, because the homocitrate is located to just below the site, and provides a hydrophilic environment for the egress of the hydrophilic ammonia.

Full details this research and the proposed mechanism are published.[Dance, 1994] The model is holistic, accounting for the essential nature of iron but not molybdenum, the limited axial connection of the cluster to protein, the exposed face of undercoordinated iron atoms as binding site, doubly-bridging sulfide ions flanking the binding face which provide

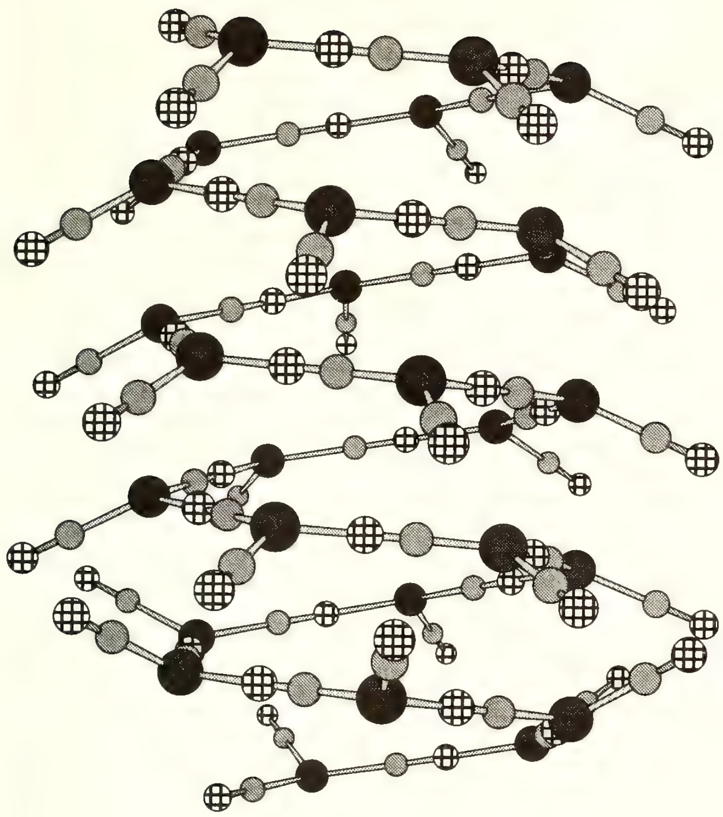

Figure 15 The proposed helical structure of $[Zn_{27}(CN)_{55}]^-$.

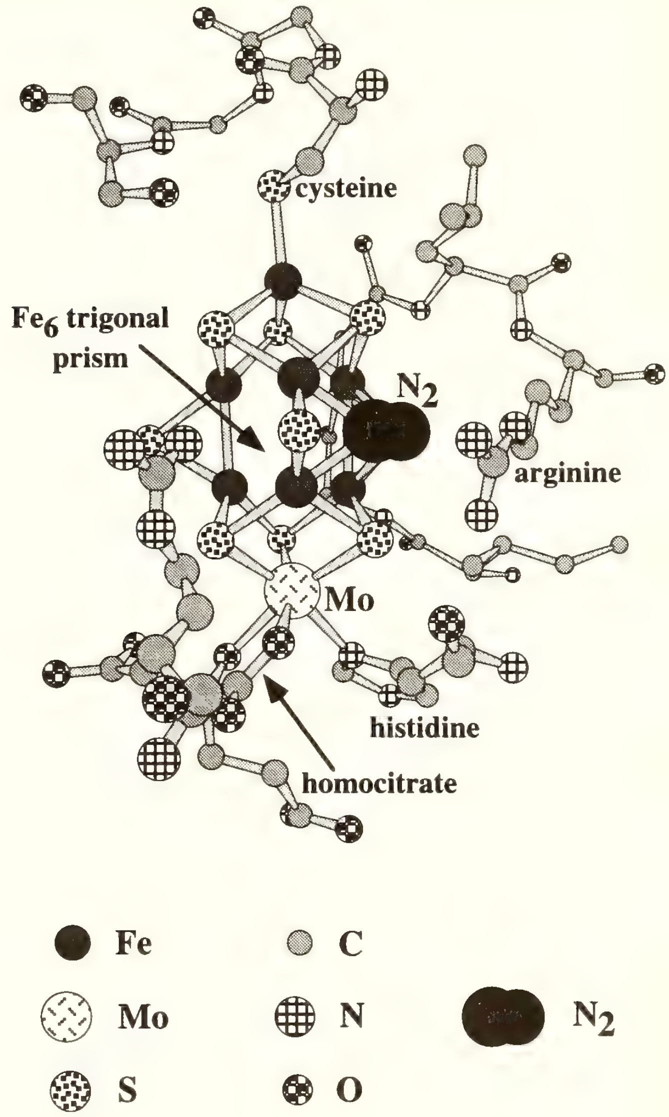

Figure 16 The Fe_7MoS_9 cluster which is the active site of nitrogenase. The cluster is connected to the protein only at the cysteine bonded to the top Fe atom and the histidine bonded to Mo at the bottom. The homocitrate which chelates to the Mo atom is an essential component. Nearby protein residues which are significant for the mechanism are marked.

proton transfer pathways, the sixfold coordination of molybdenum providing an anchor point for torsional twist of the binding site, the Fe_7MoS_9 core allowing electron reservoir action, the homocitrate as provider of local hydrophilic environment for product egress

The investigations of the mechanism of nitrogenase provide a connection between the frontier of gas phase cluster chemistry to the frontier of evolved molecular biology.

To summarise and conclude: I have shown that gas phase inorganic chemistry coupled with ion trap mass spectrometry and density functional theory enables investigations similar to those of the more conventional condensed phases, with syntheses, separations, measurements of reactivities and reactions, and approaches to structures. This research, involving the pristine state, reveals the fundamentals of inorganic chemistry, and indicates possibilities that might not otherwise have been contemplated. Certainly gas phase inorganic chemistry is provocative.

Then I have included all of the domains of the condensed phases, including the environment of a molecule which is often ignored. I have shown something of the nature and effects of the supramolecular interactions for metallo-compounds, different from those of non-metal compounds, and different from lattices containing monatomic ions. What we know as the outcomes of evolved molecular biology (that is supreme supramolecular chemistry) such as the chemistry effected by the enzyme nitrogenase, indicates that there are many further enticing processes and materials still to be developed.

I conclude that the frontiers of inorganic chemistry are indeed rich and certainly not "inorganic". The future is exciting.

Finally, I acknowledge with pleasure the contributions to this research made by Dr Marcia Scudder, Dr Keith Fisher, Professor Phil Dean, previous and current students Robert Garbutt, Garry Lee, John Cusick, John El-Nakat, Dawit Gizachew, and Ma Nu Li. Resources provided through the Australian Research Council, the University of New South Wales, and Australian Numerical Simulations and Modelling Services (at ANSTO) are very gratefully acknowledged.

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THESIS ABSTRACTS

MEnvSt Thesis Abstract

Introductory Studies of Silica Fume Released as a By-product of Electrometallurgical Processes

Elizabeth A. Cunningham

The introductory studies of silica fume released as a by-product of electrometallurgical processes which have been undertaken in this thesis included, as the central theme, a consideration of the morphological characterization of the fume particles. Using a Transmission Electron Microscope the count median diameter (CMD) was calculated to be 340Å with a geometric standard deviation (σ_g) of 1.86. The characterization was somewhat limited in scope, in that the morphological assessment included primary particle size only not aggregate size.

On the basis of the characterization of the silica fume as an ultrafine aerosol, predictions of possible patterns of deposition in the human respiratory system were attempted. The predictions were based on the findings of a literature review of the deposition of particles in the respiratory system, and attempted to reflect patterns of deposition to be expected in the general community.

The literature on the effects of silica fume inhalation on both animal and human respiratory systems was reviewed and included the results of a minor survey conducted in southern Tasmania on some aspects of respiratory health in the population living in two geographical areas of Tasmania, one of which was situated in the vicinity of a silicon smelter. The review was undertaken to provide a basis for an examination of the previous and current TLV recommendations for industry by the ACGIH. The current problems with regard to the monitoring of silica fume are discussed as well as the need for future studies in the industry.

An abstract from the thesis submitted to the University of Tasmania for the degree of Master of Environmental Studies, awarded May 1994.

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PhD Thesis Abstract: Light Scattering Studies of Microstructure in $YBa_2Cu_3O_{7-x}$ Superconductors.

John M. Long.

Raman spectroscopy and optical microscopy have proven to be useful techniques for the characterisation of $YBa_2Cu_3O_{7-x}$ and other ceramic superconductors. As the primary electrical properties of bulk $YBa_2Cu_3O_{7-x}$ superconductors are dependent on microstructure of the materials, an investigation was carried out to apply Raman spectroscopy and optical microscopy to the analysis of microstructure in polycrystalline $YBa_2Cu_3O_{7-x}$. The two techniques have not previously been used closely together for microstructural analysis of $YBa_2Cu_3O_{7-x}$. It was found that the two methods work well together. Raman spectroscopy provides much detailed information on individual grains of particular samples, and optical microscopy provides more overall, general information concerning a whole sample surface. Micro-Raman techniques were far superior to conventional Raman techniques when applied to the analysis of $YBa_2Cu_3O_{7-x}$.

Micro-Raman spectroscopy analysis was directly correlated with optical microscopy observations. Sample colours as observed through crossed polarisers were calibrated and correlated with primary sample properties such as oxygen stoichiometry and orientation of $YBa_2Cu_3O_{7-x}$ grains. The presence and distribution of impurities was determined by both Raman spectroscopy and optical microscopy.

Refinements of Raman analysis techniques were also developed. A Raman spectral peak near 335 wavenumbers (cm^{-1}) was found to have a systematic variation in asymmetry as a function of oxygen stoichiometry, $7-x$. This variation was calibrated against the position of another Raman peak near 500 cm^{-1} whose position is sensitive to $7-x$. $YBa_2Cu_3O_{7-x}$ grains can have an orientation such that in a Raman experiment, the peak near 500 cm^{-1} is weakly detected (or not at all), but that near 335 cm^{-1} is easily detected, and the asymmetry of this peak may give a measure of $7-x$, an essential parameter in the preparation of $YBa_2Cu_3O_{7-x}$ as a superconductor. Two previously published mathematical equations used to describe peak asymmetry were examined, and one was selected as more convenient for routine analysis of $YBa_2Cu_3O_{7-x}$ samples. A ratio between the intensity of the peak near 335 cm^{-1} and the sum of the intensities of two other peaks near 440 and 500 cm^{-1} was established to partly quantify grain orientation.

The partial substitution of dysprosium for yttrium in some $YBa_2Cu_3O_{7-x}$ samples was also detected by micro-Raman spectroscopy as part of their microstructural analysis.

The effect on the spectra of strong laser irradiation was also investigated. Heating caused by the incident laser beam produced one or two extra Raman peaks from crystal defects between 550 and 650 cm^{-1}, depending on the orientation of the grain under examination and its initial oxygen stoichiometry. The results are more or less consistent with previously published results of similar heating experiments.

The experiments were carried out in the context of a larger research programme on microstructural and electrical properties of polycrystalline $YBa_2Cu_3O_{7-x}$. Some of the samples from this programme were examined. Some correlations were found between the microstructural properties and previously determined electrical properties.

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THESIS ABSTRACTS

PhD Abstract: Shock Wave / Boundary Layer Interaction at a Compression Corner in Hypervelocity Flows.

Samuel George Mallinson

Hypervelocity flow over compression corners with both sharp and blunt leading edges is examined. In particular, the effects of real gas behaviour on the shock wave / boundary layer interaction at the corner are investigated. The flat plate flow, which is the datum case, is also considered in detail.

The problem was studied both experimentally and theoretically. Experiments were conducted in a free-piston driven shock tunnel with reservoir enthalpies and free-stream speeds ranging up to 19 MJ kg^{-1} and 5.5 km s^{-1}, respectively. Measurements were made of the surface pressure and heat transfer. Some flow visualization data were also obtained. The experimental data were compared with several theories that are strictly valid for perfect gas flows. The local flat plate similarity method was also extended to include real gas effects and used to predict flat plate and compression corner flow for three idealized conditions of practical importance.

Real gas effects on the sharp leading edge flat plate flow appeared to be small. For the blunt leading edge flat plate flows, the pressure and heat transfer were greater than for the sharp leading edge flows. These differences seemed less pronounced at high enthalpy. It is thought this may be due to the smaller shock stand-off that occurs for real gas flows.

The separation and plateau pressures, the upstream influence, the peak heating near reattachment and the incipient separation angle are important characteristics of compression corner flow. With leading edge sharp, the high and low enthalpy data for these characteristics compared well with each other and also with theories strictly valid for perfect gas flows. With leading edge blunt, the plateau pressure appeared to increase and the upstream influence and the pressure & heat transfer on the ramp face were seen to decrease relative to the sharp leading edge flows. The plateau pressure and upstream influence at high and low enthalpy seemed to compare well with each other. There were some discrepancies between the peak heating data for high and low enthalpy, which was perhaps due to transition to turbulence on the ramp face.

From the experimental data, the real gas effects on flat plate and compression corner flow do not seem significant. It was, however, still of interest to examine real gas effects on shock wave / boundary layer interaction. To do this, the local flat plate similarity theory for laminar hypersonic flows was extended to include real gas effects. The gas chemistry was based on the ideal dissociating gas model. It was shown that the boundary layer displacement thickness is reduced for a real gas by an amount that depends upon the energy lost to endothermic processes in the boundary layer. This suggests the extent of separation, which varies with the displacement thickness, would be reduced by real gas effects. The theory predicted the real gas effects on the pressure and heat transfer for flat plate flow to be small. For the compression corner, the theory indicated lower levels of pressure and higher levels of heat transfer on the ramp face. The latter is attributed to the reduced boundary layer thickness for the real gas.

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THESIS ABSTRACTS

Doctoral Thesis Abstract

Geological factors influencing erosion gullying in the Grenfell-Gooloogong area, mid western New South Wales.

Sara G. Beavis

The Thesis is concerned with understanding the geological influences on gully erosion. Although it is accepted that a factorial complex, comprising parent material, climate, topography, land-use and drainage basin area, defines the system, the roles of geology has been assessed by selecting sites where other variables are constant.

Extensive field surveys and laboratory analyses have formed the basis for describing quantitatively the influence of geological structure on gully pattern, orientation and density. Furthermore, field evidence has indicated that groundwater discharge, in association with major faults and/or highly fractured parent material, is of major importance in the location of gully systems.

The different parent materials, having varying mineralogy, texture, fabric and degree of weathering, influence the soil's physical, chemical and engineering properties. Mechanisms of erosion are a dynamic expression of soil properties. This relationship, although it cannot be quantified, explains the observed phenomenon of the same process producing dissimilar rates of linear extension.

The study of mechanisms led to the development of equipment to measure directly water throughflow at gully headcuts. Results strongly suggest that throughflow is the most significant process of water movement at gully headcuts, effecting detachment of material from the headcut face. It has been shown, further, that the configuration of throughflow hydrographs is influenced by the clay mineralogy of the soil.

Soil properties influence the incidence and severity of erosion gullying. Multiple regression analyses have been utilised to define statistically the relationship between soil properties and rates of erosion. It is clear from this research that the relationship is complex, and that the various geological/soil factors are interactive and do not operate in isolation. Significantly, it has been found that the interaction between, and the controlling set of, variables causing erosion, are unique according to parent rock associations.

Multiple regression analyses have quantified further the variability of controlling sets of factors. When hydrological parameters are held constant, over 90% of the variance in the rate of linear extension of gullies is accounted for by soil properties. Even taking the hydrological factors into account, soil properties account for over 50% of the variance.

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THESIS ABSTRACTS

Master's Thesis Abstract

Parameters Affecting S.I. Engine Knock

Petros Lappas

A high speed, single cylinder spark ignition engine with an optically accessible combustion chamber, was used to study the influence of various engine parameters on knock tendency. The test engine resulted from major modifications made on an existing engine situated in the thermodynamics laboratory of the Mechanical Engineering department at the University of Melbourne. Knock was assumed in this study to be initiated by the spark plug as the ignition source ("Spark Knock"). The parameters influencing knock that were examined were inlet air temperature, coolant temperature, engine speed and combustion chamber shape. An improved understanding of engine factors affecting knock, should lead to methods for its reduction. Knock reduction is crucial in developing spark ignition engines with higher compression ratios that offer greater thermal efficiencies.

To avoid engine damage, incipient knock was produced corresponding to sudden acceleration of the flame traversing the fuel-air charge in the combustion chamber. Thus, the knock tendencies of two combustion chambers were compared. The first combustion chamber contained a "swirl vane" (close to the inlet valve) whilst this vane was removed for the other chamber. Numerical results including pressure and crank angle data for various knocking conditions that were obtained from the swirl vane combustion chamber, were manipulated and compared with theoretical expectations. Data manipulation entailed visual screening of important points of the "raw" data, and numerical filtering. The data was then processed by a "reduction" program to convert the filtered data into an acceptable form with SI units.

The spark advance required to initiate knock was found to increase with engine speed. The spark advance increase was approximately 10 degrees for each 200 r/min increase in engine speed over the range tested. This is because, the time for which the end-gas is exposed to extremes of pressure and temperature during combustion, reduces with engine speed and lessens the chance of knock unless the spark is further advanced.

Combustion duration (in ms), which is a direct indication of the time for which the end-gas is exposed to extremes of pressure and temperature, was evaluated with the aid of computer code developed by the author to determine important information including mass fraction burnt history. The code was based on a combustion model that assumes separated regions of burnt and unburnt gas in the combustion chamber. The flame shapes observed in combustion photographs taken confirms this assumption, thus validating the model used.

Despite the well known phenomenon that knock tendency increases with inlet air temperature, there was no relationship detected between inlet air temperature and knock advance. This is because of the errors associated with the determination of the knock advance due to a) necessary haste whilst increasing the spark timing (until knock is initiated) because of imminent cylinder overheating and b) the non-proportional alteration of spark advance due to eccentricity in the advance screw mechanism. For similar reasons, the expected increase in knock sensitivity with cylinder head coolant temperature was not detected.

Even though all tests had a similar degree of knock, higher NOx levels were recorded in tests with higher engine speed and inlet air temperature, because of the higher pressures and temperatures reached in these conditions.

The observations from the swirl vaned combustion chamber did not conflict with established theory on the causes of spark knock. Combined with concepts expanded by the author, this knock theory (which is intimately connected to autoignition theory) was applied to combustion photographs for both combustion chambers to predict which one was the least likely to knock. Computer code was written to demonstrate the insignificance of heat transfer relative to burn-rate. On the basis that autoignition is highly dependent on burn-rate and less so on end-gas heat transfer, the combustion chamber without the swirl chamber was predicted as the one least likely to knock.

An abstract from the thesis submitted to the University of Melbourne for the degree of Master of Engineering Science, August 1995.

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BIOGRAPHICAL MEMOIR

ALAN HEYWOOD VOISEY
1911-1995

Professor Alan Voisey, former Head of the Department of Geology, University of New England and the School of Earth Sciences, Macquarie University, died suddenly in Sydney on 15th April 1995, 4 days after his 84th birthday. His association with the subject he loved spanned 65 years and Australia has lost one of its great teachers of Geology.

Alan Heywood Voisey, an only child, was born on 11th April, 1911 at Cessnock, the day of a mine disaster. His primary school days were at Macksville and in 1922 Alan became Dux of the School. However because the family could not afford to send him as a boarder to high school at Kempsey, Alan repeated the final year of primary school, in order to apply for and be awarded a bursary, worth 40 pounds a year. In 1923 he was also Dux of the School. At the end of his secondary education at West Kempsey Intermediate High School, in 1928, he was Dux and in his Leaving Certificate examination topped the State Honours List in Geology.

In 1929 at the onset of the Great Depression, Alan entered the Faculty of Science at the University of Sydney with the aid of a Sydney Teachers Training College scholarship. It was here that he was to study and be influenced by the "greats" of Australian geology. Professor T. W. Edgeworth David who had held the Chair for 33 years, vacating it in 1924, was still there, active, revered and influential. Others on the staff included W. R. Browne, L. A. Cotton, L. L. Waterhouse, G. D. Osborne, W. S. Dun and Ida A. Brown. Alan not only excelled at his studies, but formed attitudes and ideals that influenced and served him well throughout his life. Tales of these times were oft repeated by Alan with relish to the generations of university students he taught. Alan's students remember well the geology excursions they attended, with Alan holding forth, around a campfire or at the local pub, about his student days, of the Sydney staff, and of the academic rivalries with his fellow students, in particular his lifelong friend Sam Warren Carey. There was more to his stories than just the events; it was his sincerity and friendliness, his deep and abiding respect for the ideas and teachings of others, his love of geology, and his sense and appreciation of history in passing on information.

After four years at Sydney, Alan graduated in 1933 with a B.Sc.Degree, First Class Honours and was awarded the University Medal in Economic Geology. He shared with Sam Carey the Coutts Scholarship for Proficiency in Science. Being under bond to the NSW Education Department, he was required to attend the Teachers Training College during 1933. However, instead of being appointed as expected to a secondary school in early 1934, the depression and lack of Government funding meant that Alan spent six months unemployed until he was appointed as a primary teacher to Greta Public School, nearby his birthplace. Greta was a mining town, where all the mines were closed and virtually the only people in employment were government employees. This was an extremely difficult time for Alan and he was delighted when at the end of 1934, he was offered a temporary position with a mining company in Victoria, and soon afterwards, a position with the newly formed Aerial, Geological and Geophysical Survey of Northern Australia as Assistant Geologist. During this time, Alan developed skills of regional mapping, interpretation of aerial photographs, and the ability to "rough it" in harsh and uncompromising terrains.

In 1937 and 1938 a Macleay Fellowship from the Linnean Society of New South Wales enabled Alan to return to Sydney University for Master of Science research under Dr W. R. Browne. He worked on Upper Palaeozoic rocks in the Wingham area of the Manning River district, and it was here he met Phyllis Cox of "Colraine" Kimbriki, who became his wife in 1938. In his memoirs (Voisey 1991), he acknowledged "..my gratitude and thanks to my wife, Phyllis, who, in one way or another was involved in almost everything I did - whether she approved or not, over more than fifty years. Besides caring for me and our children, Yvonne and Lynette, and where possible for our grandchildren, she welcomed and entertained at home my colleagues, particularly geologists - dirty or not!"

New England University College was established in 1938 as part of Sydney University and in 1939 Alan was appointed lecturer in Geology and Geography. He was to scrounge, borrow and buy equipment, as 1939 was the first year of teaching of geology and geography. Initial student accommodation was the laundry at "Booloomimbah" and transport for student excursions was in Alan's sturdy 1924 Dodge tourer "Bertha". The Armidale years (1939-1965) were productive for Alan in terms of research and in 1954 was awarded his DSc from the University of Sydney. Later research papers reflected the emergence of geosynclinal theory to plate tectonics. Alan and family also made sabbatical visits to Antioch College, Ohio in 1952-1953, ANU in 1960, University of Otago in 1961 and Eastern Michigan University 1964-1965. In the period 1939 to 1965, the teaching staff increased to 5 and saw the College become an autonomous university. These were years of proud achievement for Alan, for in that time he had attracted a dedicated staff of high research calibre. To cope with increased students and staff, Alan negotiated and helped design a new building for the Department of Geology, opened in 1960. The centrepiece of the building, was a stone entrance wall that consisted of an E-W cross-sectional mosaic of rocks from the New England Fold Belt. Alan had overseen the collecting and laying of each hewn block. He would delight in showing it to visitors and students at every opportunity.

Alan was an active participant in the changes to the secondary school curriculum of N.S.W. during the years that Dr H. S. Wyndham was Director General of Education. As the geologist on the Syllabus Committee, Alan was instrumental in establishing an integrated course in Geology and Biology as from 1962. As Chairman of the Geology Group, he contributed a large part of the text book "Science for High School Students" produced by Professor Harry Messel and the Nuclear Research Foundation in the University of Sydney.

In 1964, as a result of his experiences in New England and his interest in education, Alan was invited to form part of a government committee to advise on the establishment of a third Sydney University — Macquarie. His enthusiastic input and spirited stand in promoting Geology and Geophysics ensured that many of Alan's ideas were adopted in the Regulations. He was appointed as Professor of Geology and Head of the School of Earth Sciences in 1966, and teaching commenced in 1967. As in the case of New England, Alan set about to appoint young and vigorous academics to devise and teach courses to the students who numbered in the hundreds. His policy was never to turn a student away, and unlike more traditional schools in the University, Earth Sciences, consisting of Geology and Geography continued to grow. By 1971, just 4 years after teaching commenced, there were 36 lecturing staff and 11 tutoring staff, a remarkable achievement.

By 1971 and with many of his academic expectations realised, Alan retired, but instead of opting for the quiet life, he plunged into the world of mining and finance. This was a vastly different world from that of academia, where he had spent much of his life. Both the rewards and the lifestyle were different. However, Alan's long and varied experience and knowledge meant that he was invaluable to the burgeoning mining developments of the seventies and eighties. His experience in geology and his contacts in the mining world, some of whom were his former students, resulted in Alan being appointed to directorships or consulting for many companies including Mining Finance Corporation, ICI Australia, Oakbridge Limited, Era South Pacific, Minerol Investments, Negri River Corporation, Sedimentary Gold, Cracow Gold and Sedimentary Holdings. It was a lifestyle he was to follow until 1987.

The University of New England, honoured him with an Honorary DSc in 1978 and in 1980 the Geology Department formed the A. H. Voisey Club. At that time, there were 450 graduates in geology and the purpose of the club was to keep in touch and contribute to the growth of the Geology Department. Macquarie University awarded him an Honorary DSc in 1993, the 25th year of teaching.

The New South Wales Division of the Geological Society of Australia, now awards an annual A. H. Voisey Medal to "a younger member of the Society for outstanding research work". Alan joined the Royal Society of New South Wales in 1933, was for some years a Member of Council, and President in 1966.

Throughout his life Alan continued to make friends in all walks of society. His love of geology was a major facet of his life. However, another most important aspect was his attitude to, and his relationship with, his students. He was imbued with a determination to ensure that his students came to love geology and that one and all achieved to their maximum potential. Equally importantly, Alan was proud of the achievements of his students and took pride in their successes. He was a man who set goals and steadfastly pursued them throughout a long and useful life. The following saying has been attributed to Alan: ... "I never took on a fight that I didn't intend to win". Most members of staff who have sat through School meetings with Alan in the Chair would agree with those sentiments.

His death occurred at the end of a busy week which included a Geological Society, N. S. W. Division meeting, a Chancellors' luncheon at Macquarie University, and his 84th birthday party attended by his wife, their two daughters, two of his grandchildren and two of his former University students. He died just four days later. His mind was always active and clear, he had no regrets, he had lived his life to the full.

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References are to be cited in the text by giving the author's name and year of publication. References in the reference list should follow preferred method of quoting references to books, periodicals, reports and theses, etc., and be listed alphabetically by author and then chronologically by date.

Titles of journals should be cited in full – *not* abbreviated.

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BRICKS, BRAWN AND BRAINS - TWO CENTURIES OF GEOLOGY & ENGINEERING IN THE SYDNEY REGION

D.F. Branagan

ABSTRACT. Since the beginning of European settlement both geology and engineering have played important roles in the development of the "made" environment. Contributions by the likes of John Busby, George Barney and Thomas Mitchell (each broadly trained and experienced) prior to 1850 saw an essentially unified approach to problems of road construction, harbour reclamation and water supply and their solutions. The rise of the civil engineering profession in the latter portion of the nineteenth century coincided with virtual neglect of geological aspects of projects such as bridge and dam construction. Perhaps more by good luck than good planning there were no major disasters. However, during the same period, applied geologists, with few exceptions, devoted their attention to mining rather than to the relevant aspects of civil engineering, and perhaps saw no need to make useful contributions. By the 1920s the scale of projects, introduction of new methods and equipment, and some failures, began to bring the two professions together. The major project which heralded the present period of co-operation was the Warragamba Dam, built between 1939 and 1960. From the 1970s there was more co-operation and geologists contributed with the mapping of significant fracture systems and dyke intrusions which affected planning and construction. From 1970 there was also greater combined study of the significance and measurement of horizontal stress in the Sydney rocks. Nevertheless there are still failures of fact and communication, and Sydney still lacks a central scheme for the gathering and dissemination of geological data for the civil engineering profession, for town planners and concerned citizens.

INTRODUCTION

In July 1996 we remember the 175th anniversary of the Philosophical Society of Australasia. One of the original members of that Society in 1821 was Alexander Berry, who did not need to take up Thomas Mitchell's later comment that "every settler is under the necessity of becoming a geologist" as he was already knowledgeable about geology and a very practical man to boot. Berry was the first to report on the unconformity at the base of the Sydney Basin sequence (Berry, 1822). Berry set up his south coast trading post at Coolangatta near the mouth of the Shoalhaven River, where he also put his knowledge of geology to use, when after a fatal disaster at the mouth of the Shoalhaven River on 21 June 1821, he sailed up the Crookhaven River, which had an accessible mouth, and dragged his boat across a sandspit into the Shoalhaven. A few days later he left Hamilton Hume (who was also associated with the Philosophical Society) and three other men to cut a passage through the spit. Using only hand tools they cut Australia's first canal, some 200m long in just 12 days. This was widened by natural activity over the years and is now the real entrance to the Shoalhaven River (Cambage, 1921; Jeffcoat, 1988).

Mitchell himself is the epitome of using geology and his ability to relate together the two disciplines of geology and engineering is one of the great success stories of Australian science and technology (see later). The infant colony of New South Wales was blessed with practical men as leaders in its earliest years, Arthur Phillip setting the example, based on his experience as leader in the small Portuguese colony at Colonia on the River Plate, now part of Uruguay (Vallance and Branagan, 1969; Branagan, 1994).

This paper will not discuss the relations between mining and geology, which have received attention in earlier papers (Branagan, 1972a), but

considers geology and civil engineering and deals essentially only with the Sydney region, extending to the edge of the Blue Mountains and the Hawkesbury River.

In Branagan (1972b) I suggested that five basic areas of geological information should be available to the engineer and town planner. They are: foundation conditions, availability of materials, transport, water supply/sewerage and visual aspects of the landscape. That paper discussed the geological controls on the development of Sydney, and attempted a quantitative rating of geological conditions in relation to engineering requirements, while comparing the geology of Australian capital cities. Listed simply for this paper the relevant topics are materials, water, surface conditions and the underground.

MATERIALS

Bricks

One of the first demands of the First Fleeters was materials for construction of permanent buildings, displacing the temporary timber and canvas structures. There was need for clay for bricks, stone for various purposes and lime for cement. Vallance (1975) has conveyed the excitement that eventuated when clay from Sydney (and from Lion Island) (Vallance, 1985) recommended to Governor Arthur Phillip by Abbé Mongez of La Perouse's Expedition as certain "to make good china" was sent to England, was tested by the great Josiah Wedgwood and was pronounced to be unique! The new colony had produced a new mineral, *Sydneyia*, to set besides new animals and plants! German mineral chemists were more sceptical, and it was not long before Martin Klaproth showed that the clay was ordinary

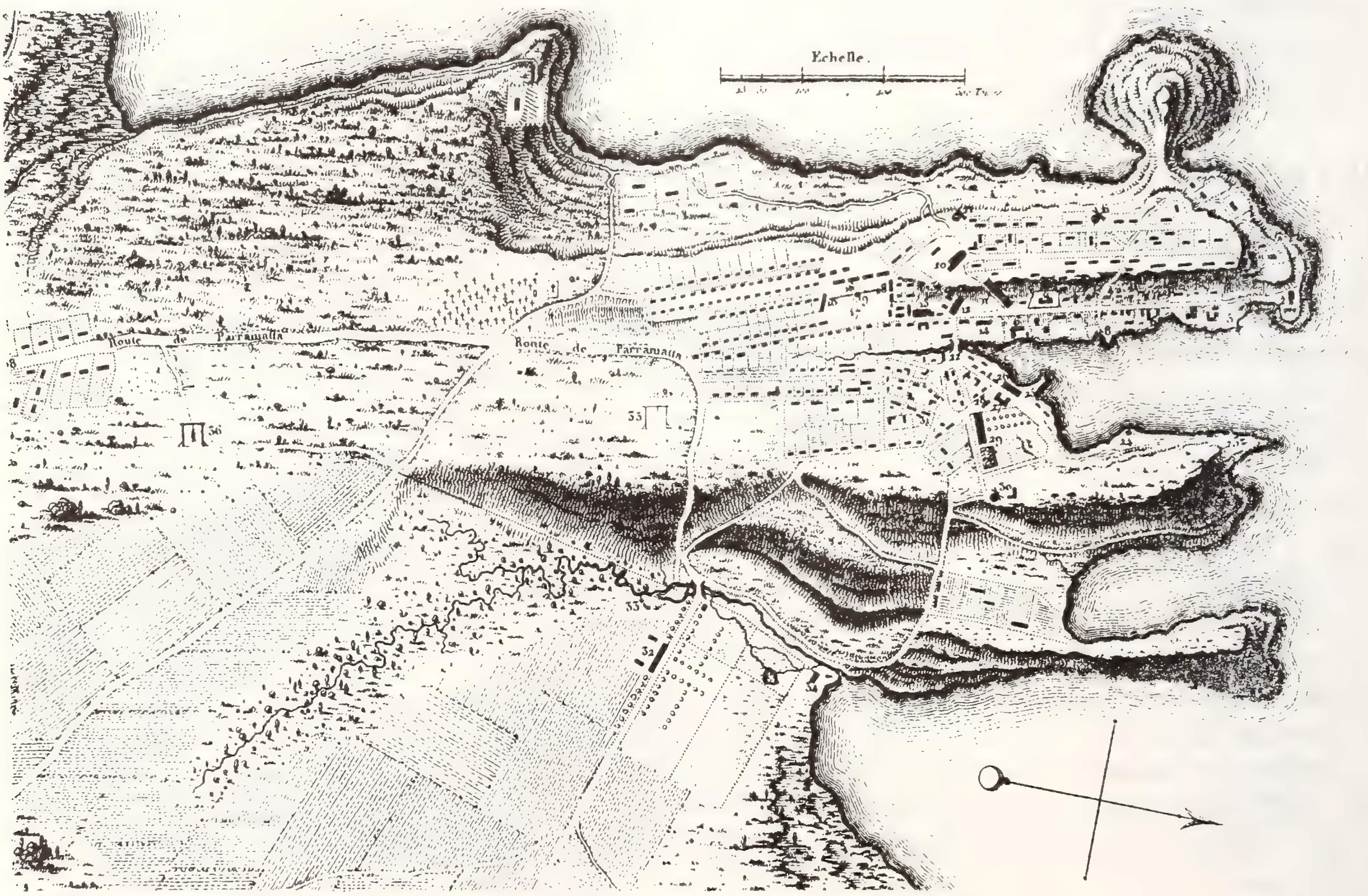


Figure 1. 1802 French map of Sydney showing bricks pits at Woolloomooloo (No. 33) and at Brickfield Hill (at the south end of the map on Route de Parramatta).

enough, and Charles Hatchett followed suite in England in 1797 showing that Wedgwood's chemicals were contaminated.

However this did not concern the colonists who had to get on with the business of brickmaking. Although we hear much of the shale of Brickfield Hill (the shale fields were about the present Pitt and Campbell Streets) as the early source of bricks shown on Phillip's map of 1792, I suspect that easier sources were found in the alluvium along the banks of the stream draining into Woolloomooloo Bay, as shown on Lesueur's map of 1802 (Figure 1). Kelly and Crocker (1977) provide a succession of maps that give some indication of the various sites where materials were quarried or treated from the beginning of European settlement until 1900. Andrews (1991) states categorically that the first hand-made convict bricks were made under the supervision of James Bloodsworth in March 1788 two miles from the settlement at "Long Cove, today known as Farm Cove". Bloodsworth almost certainly used the brick moulds brought out by Governor Phillip. A brickmaking facility (belonging to Commissary John Palmer) operated there at least until 1822. Bloodsworth also seems to have been responsible for locating the Brickfield Hill source with its supply of fresh water. At Parramatta too there was a small kiln on the banks of the Parramatta River, below Old Government House as a painting of 1791 shows (Steven, 1988, p.47). This kiln, I suspect, would also have first used the alluvial clay of the river bank, rather than the Ashfield Shale, although the latter certainly occurs close by. The opeations of this brick kiln at Parramatta were overseen by another convict, John Becket; it employed 52 people and produced 25 000 bricks weekly, but the quality of theses bricks proved poor (Andrews, op.cit.).

By the 1820s a number of private pits were operating in the Sydney region. In the years that followed the Wianamatta Group of rocks (particularly the Ashfield Shale) was the source of bricks from many sites south and north of the harbour and gave the suburbs of Sydney much of their flavour. Few of the quarries have been preserved, but we do have a memory to this important, but always conservative, industry in the Sydney Park at St. Peters (Figure 2). Aspects of the more recent geology and technology of brickmaking properties of the shales of the Sydney region are discussed by Herbert (1979).

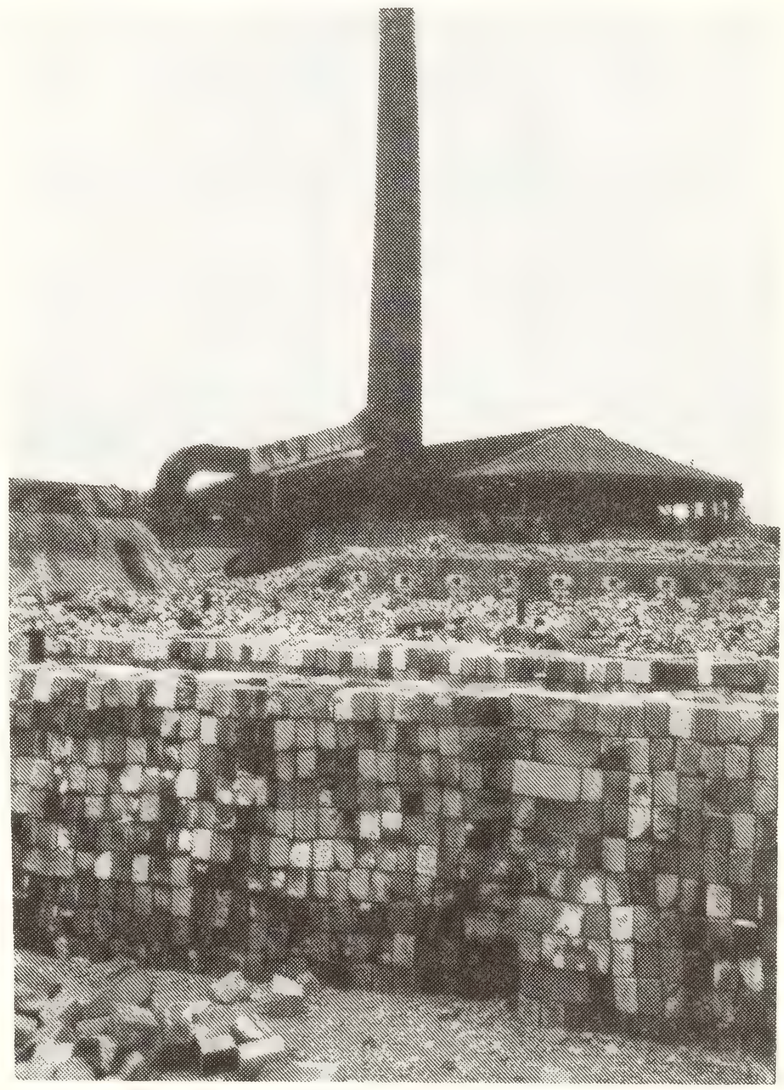


Figure 2. St. Peters Bricks. The end of production. The area is now a heritage site.

Lime

Lime was to be a constant source of worry, as the shell deposits (some undoubtedly Aboriginal middens) around Sydney Harbour were rapidly used, as later were the deposits at the mouth of the Hunter River. According to Thomas (1979) lime kilns operated near Bennelong Point and near the north end of Kent Street before 1823. Some lime could have been brought from Norfolk Island, and indeed may have been, for we see one interesting use of stone from Norfolk Island at Hambledon Cottage, Parramatta. This is a filter "tank" of calcarenite used for purifying water. The lime

shortage however was not to be relieved until after 1815 when George Evans discovered limestones west of the Blue Mountains, and Limekilns, north of Bathurst, came into operation, being visited shortly after work began by Governor Macquarie and his entourage (Carne and Jones, 1919).

Sandstone

In parallel with brickmaking was the use of stone. In fact stone quarrying may have preceded brick making, as the map prepared by a convict in June 1788 shows a quarry close to the present Opera House site, while Thomas (op. cit.) shows one towards the northern end of Kent Street. Many others followed east and west of the growing settlement. What is sure is that "Sydney Sandstone" became well accepted as a fine building stone for many purposes, and its use spread well beyond Sydney to Twofold Bay, and even New Zealand, and has given the city of Sydney much of its character, even if today it tends to be overshadowed by various showy imports!

Figure 3. Quarry in contact altered sandstone, North Bondi. (University of Sydney Archives).

Hawkesbury Sandstone has been used not just for ornamental purposes but as cut stone in masonry dams, crushed stone for road base, and, when hardened by contact metamorphism, for railway ballast (Figure 3). However its quality does vary, as the weathering of buildings shows us. Although examined microscopically by Woods (1882), Curran (1891) and others towards the end of the 19th century, micropetrology was not used in an applied sense. However Liversidge (1895a & b) carried out experiments on the waterproofing of sandstones and bricks with oils, and incidentally also studied the porosity of plasters and cements. Baker (1915) waxes lyrical on the qualities of the Hawkesbury (Sydney) Sandstone as a building material, but comments that little had been written specifically on its properties or those of various other Australian stone materials. However Baker and Nangle (1909) a little earlier did carry out a series of heat and pressure tests on blocks of various stones, including some sandstones from around Sydney.

Not until 1959 was there a detailed study of the petrology of the Hawkesbury Sandstone by Golding, published in the Society's Journal. This was followed by some interesting physical tests by Robson in 1978. There were also important studies by O'Brien (1969), Pells (1977, 1985), Gibbons (1981), Riley (1994) and others, some of these dealing with problems of weathering in general, or particular problems such as salt efflorescence.

There have been many quarries in the Hawkesbury Sandstone (Van Heeswyck, 1976), including the interesting ones at Mosman and at Cockatoo Island (referred to later). Narrabeen Group sandstones in the Gosford area began to be used in quantity following the completion of the Homebush - Hamilton Railway in the 1880s.

Igneous Rocks

Igneous Rocks attracted geologists from earliest times. Thomas Mitchell was intimately involved in developing the Dundas quarry, one of the first sources of road metal in the colony, later

described by C.S. Wilkinson (1879), David et al (1893) and in the 1940s by F.N. Hanlon (1947). Part of the quarry face is still exposed at Dundas. However, even earlier, the French geologist Lesson (1824) had commented on the larger Prospect occurrence, which was visited in 1840 by J.D. and W.B. Clarke (Dana, 1849). H.S. Jevons et al (1911), Wilshire (1967) and others continued the interest in the Prospect intrusion, which is still being quarried. Geology since the 1960s has made a significant contribution to the economics of quarrying at Prospect.

Significant quarrying began at Prospect about 1883 by a Mr. Sperring, the face being drilled by hand, shot out and broken down by a 16lb spalling hammer: it was then broken into 2inch metal by a small 21lb hammer, this method of operation continuing until 1900. In that year Lewis Litton and Arch Turnbull, who were operating a crushing plant at Emu Plains, bought the quarry. The face was then drilled by steam-operated rock drills for primary blasting. In 1902 a railway was built from Toongabbie. This operated until 1946, and was used for instance for the direct transport of aggregate to Waterfall for the Woronora Dam (Blacktown Technical College, 1976). The availability of exposures was most useful to the geologists (Jevons et al., op. cit.), but there seems to have been little call on their expertise in relation to quarrying until the 1950s.

Morrison (1904), Minty (1959 and 1964), Wallace (1971), Adamson and Taylor (1976) are important sources on the construction materials of the region.

WATER

John Busby can be rightly called Australia's first Engineering Geologist. Busby came to Sydney, at the age of 58 in 1824, after a successful career in England and Scotland, where he was greatly in demand as an adviser and practical builder of drainage and water systems. His original appointment in the colony was to deal with mineral occurrences, and he had some hopes of being financially and practically involved in the privatisation of the coal mines at Newcastle (Branagan, 1972a).

However he was soon embroiled in providing a safe and adequate water supply for Sydney. Busby has been poorly treated by writers, accused of incompetence and fear of his convict workers (Beasley, 1988, Jeffcoat, 1988), whereas the record shows his expertise and dedication in the face of bureaucratic resistance or indolence.

As early as 25 March 1824 Busby was putting forward his ideas on water supply for Sydney, recommending boring rather than shaft sinking to obtain preliminary information about the quantity and quality of water available in the area. Water from the Tank Stream was collected in three tanks cut out on the stream bank, close to the present intersection of Hunter and Pitt Streets. These tanks were fenced to reduce pollution. They can be clearly seen in a painting by Edward Dayes, which is accompanied by an explanatory plate (Flower, 1975).

Busby, having convinced the Colonial Secretary of the viability of his scheme to bring water from the Lachlan Swamps (the present Centennial Park) to the city, began in Hyde Park in September 1827 with an open-cut. This extended 1570 feet, built up with ashlar covered by stone flagging [brought by cart from a "quarry on the east side of the Government domain"], and flagged "at such places as found necessary.... a series of shafts on the line of the tunnel was then decided on and ten were marked out. By October 1831 4732 feet of tunnelling, averaging 6 feet high and 3 wide, had been completed (Busby, 17 Oct 1831). Busby had contemplated that the quality of water coming from the tunnelled rocks might be poor compared with the lagoon water to be tapped, so he envisaged that pipes would be required. However he found to his delight that the rock water quality was excellent, and this water in fact supplied the town well before the completion of the project. Hard sandstone between pits 7 and 8 required blasting in 1828, causing Busby to defend

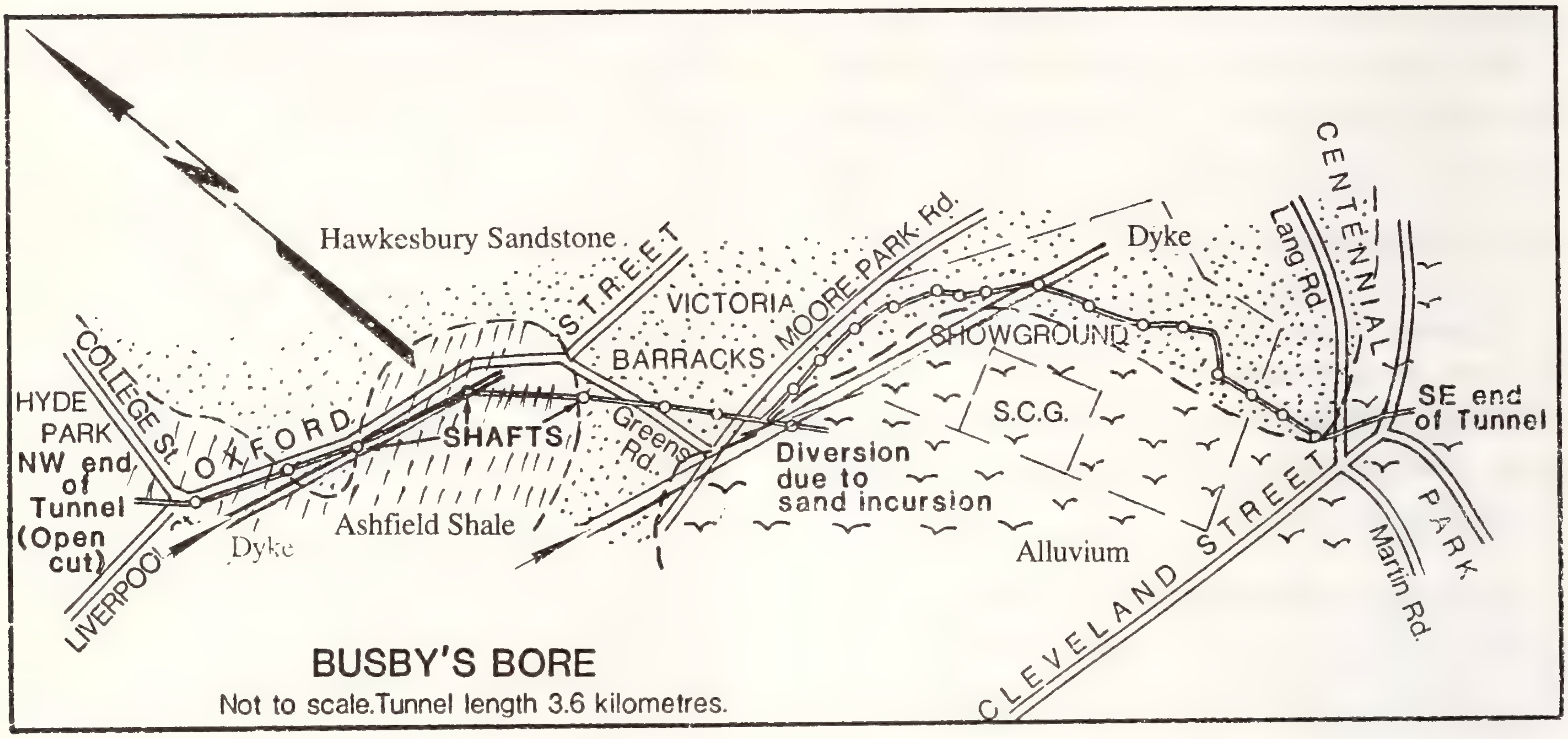


Figure 4. Busby's Bore showing location of shafts and geology encountered.

the "enormous expenditure of gunpowder" because of the "enclosed specimen" which was "almostThere was thus "no reason to suspect the embezzlement of gunpowder". A very different problem occurred between "Pits 4 and 5 [where] it was necessary to construct a brickway one hundred and thirty feet in length, in consequence of a clay vein which runs nearly parallel with the tunnel" . This probably was the result of intersecting a dykewhich runs nearly parallel to Oxford Street (Branagan, 1969).

In the following six months (to July 1832) Busby encountered considerable problems as the tunnel had influxes of water and large inflows of sand near the northern end of Moore Park, because the miners withdrew supporting timber too early. Consequently Busby decided to change the direction of the tunnel to remain in rock, as along the original route the rock was rapidly becoming deeper. In fact the tunnel was diverted at least five times because of encountering sand (Figure 4).

The irregularity of the sandstone/sand interface in the eastern suburbs of Sydney continues to present foundation problems for the engineer and builder, as shown in sites as diverse as Randwick, Bellevue Hill, Dover Heights, University of New South Wales, Kippax Street (near Central Railway) and Double Bay there may be erosion during periods of flood rain (Branagan, 1986). Many of these problems could have been averted and considerable savings made by the systematic preparation and publication of detailed engineering geology maps.

During the early stages of Busby's major project the Tank Stream had already been abandoned as a source of drinking water and although, as Keele (1908) points out, there were at that time also professional water-borers in the colony, water had to be transported to the city from the Blackwattle Swamp (Broadway) and the Lachlan Swamps. However Busby was requested to improve the water supply in the meantime by a system of public wells in the city, although he pointed out to the Governor that such wells would draw water away from already established "private" wells. T.H. Scott (1824) noted that the water in wells "being not more than 30 feet deep, the water is not good", but for one, whose location is not given, he states "one well, sunk 82 feet to a great mass of sandstone, gives excellent water".

Nevertheless Busby recommended 6 wells to depths of thirty feet at Barracks Square, Market, King and Pitt Streets to be completed by free men in a month, but he warned against taking any of his miners for the work (Busby, 25 January, 1828). One well was completed by 21 March 1828, the others a short time later. However Busby was somewhat put out when a worthy of the town sued him for damage to his carriage, which tipped up on some of the excavated clay, and the government refused to indemnify Busby!

One of Busby's wells was discovered during the excavations for Wynyard Station in 1927. It was 30 feet deep in solid rock with "wooden piping so neatly dovetailed that the joints were still watertight" - a century-old tribute to Busby's engineering (Anon, 1962).

Sutton (1992) indicates that Major George Barney completed Busby's Bore water scheme. Barney attested to the good work done by Busby and in consequence (with the support of a large number of Sydney's residents) Busby was paid a gratuity of £1 000 in addition to arrears of salary owing to him (Walsh, 1966). Nevertheless Busby did not spend all his efforts on the water scheme. We find him advising the Governor also on the removal of rock bars in the Parramatta River close to its tidal limits near Rosehill, a matter that also involved Barney a few years later.

The story of the construction of the third water supply for Sydney, the Lakes Scheme, during the 1850-60s, has been well told by Smith (1868), Henry (1939) and by Aird (1961), although there are many aspects still worth exploring. There were official enquiries about new sources of water as early as 1847 as Sydney grew. A similar Enquiry at Parramatta in 1849, at which Rev. W.B. Clarke (1849) gave evidence, led to the construction of a 15m high dam there in the next decade (see below). Henry and Aird (ops. cit.) deal with the problems of the engineers in constructing the dams in the Botany sandhills, dams which still remain, albeit modified in the intervening years. One dam (the Engine Pond, (a water puddle dam) close to the shores of Botany Bay) had been built by convict labour in 1838, but the others were not considered until 1862 and were finally designed by the City Engineer Edward Bell in 1867. Construction of these earth dams, built with timber by-washes, began the same year. Many of the dams failed in the following year but were reconstructed about 1873. Some were badly damaged again in July 1931 but were restored.

In the 1860s and 1870s the Royal Society (and its predecessor) devoted considerable time to the discussion of Sydney's water supply. While the "visionaries" looked to the Upper Nepean, there were those who envisaged damming Cook's River, and more particularly George's River, somewhere not far above where it entered Botany Bay. A small dam had been built much further upstream on the George's River at Liverpool in 1837, probably designed by David Lennox, who is more renowned as a designer and builder of bridges. The 1867 Commission included Professor John Smith, Edward O. Moriarty, P.F. Adams, F.H. Grundy, T. Woore & W.C. Bennett (all with strong engineering leanings), and it considered possible sources on the Grose River, Warragamba River, Georges River, Upper Nepean River & Cataract River. The last named had two alternatives - a high level large dam and a smaller low level structure linked to a holding supply at Prospect. This scheme was the one finally chosen.

Other suggestions looked at were the Loddon River & Maddens Plains, Wingecarribee Swamps, Erskine Valley, a tributary of the Nepean, and wells on the Botany Reserve, while an alternative to Prospect, holding reservoirs at Kenny Hill, was also rejected. This alternative proposal came from F.B. Gipps (1880) who gained considerable support from the media. To some degree Gipps' scheme was inspired by his opposition to E.O. Moriarty, designer of the Prospect scheme, who lacked academic qualifications unlike Gipps. William Clark, an engineer who came from England in 1876 was appointed "external arbiter" for the schemes. Moriarty must have been delighted to be able to pour scorn on Gipps's

proposal when it was shown to have considerable technical deficiencies (Keele, 1908).

The Legislative Assembly published an important review on the "The Water Supply for Sydney and Suburbs" in 1878 with various suggestions considered, including Richard Sadlier's earlier (1852) proposal for a tunnel from the Nepean River to George's River, while Thomas Holt resurrected Sir Thomas Mitchell's 1850 proposal for a dam on the George's River. A report by Archibald Liversidge on Water Quality was also appended.

Some of these alternative suggestions were brought into play as Sydney grew. The scheme for wells on the Botany Reserve was investigated by Glenister Shiel in 1942 as a potential emergency water source for Sydney should the war require it (Figure 5).

The Hudson Brothers' amazing achievement of building a temporary supply pipeline in six months (1885-6) has been documented by Dorter (1961), but this involved little geological work.

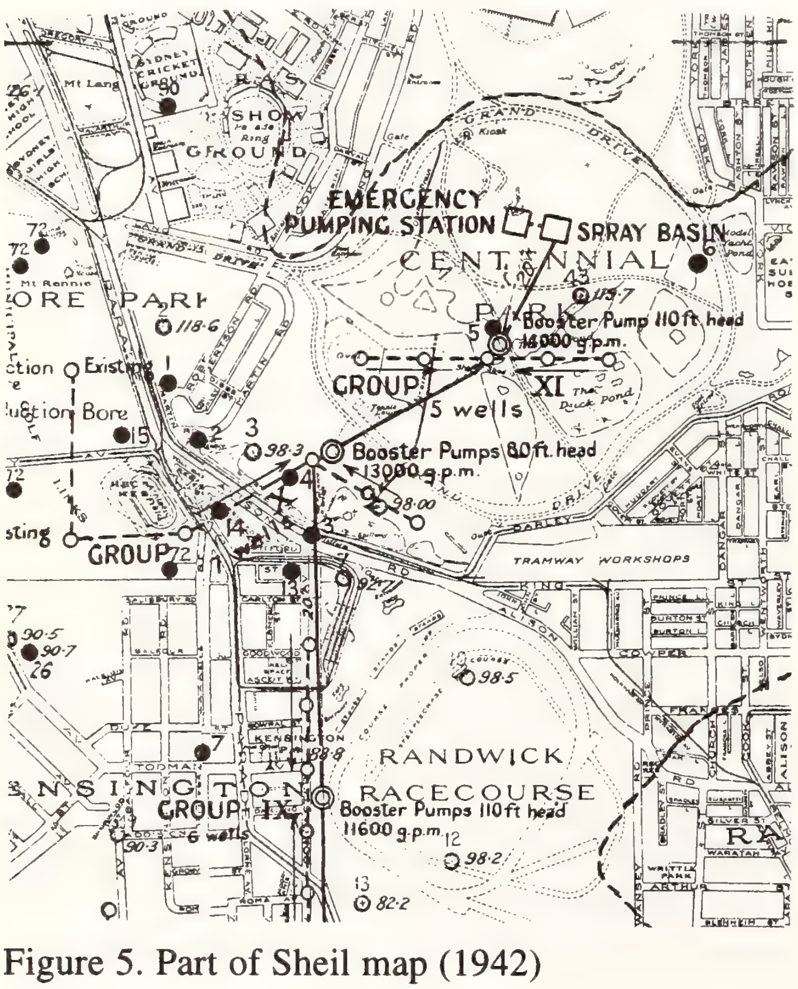


Figure 5. Part of Sheil map (1942)

ROADS AND BRIDGES

"The Construction and Preservation of safe and commodious High-ways is a matter of great and general Importance, and tends greatly to increase Commerce, and promote Civilization." (proclamation of Governor Lachlan Macquarie, *Sydney Gazette*, 6 April, 1811.). It is obvious that geology plays an essential part in the placing and operation of roads and railways. The natural surface variations, the availability of suitable materials to ensure good travelling conditions, the underlying strata and the topography each affect to some extent every road and railway.

Thus the crossing of the small Tank Stream was regarded as "a work of the first public importance". The cornerstone of the first stone bridge over the Tank Stream at Bridge Street was laid on 1 July 1803 by Governor P.G. King. This 24 feet long arch structure was begun a little earlier, when "a number of Masons and Labourers were employed in sinking the foundations" (*Sydney Gazette* 5 June 1803). However things did not go well. In December 1803 the commodious stone house of the contractor Isaac Payton was auctioned "to defray the Expence of finishing the New Bridge, which from a Breach of Contract is necessarily taken in hand bye Government". When the "centers" were removed on 5 January 1804 "a number of spectators beheld the work with much agitation, as an opinion had been formed that the arch was not likely to stand". Despite the hope that the bridge would be a lasting monument to industry and "early improvement" the poor workmanship, combined with heavy rains, caused its collapse the following October. Being in a key position it was repaired soon after, with further attention by Lt. William Minchin in 1806.

Thomas Mitchell and Roads

Thomas Mitchell had a great eye for the landscape, as his wonderful sketches show. This stood him in good stead in his placing of roads, and particularly in his solutions to crossing the natural topographic obstructions leading to the plateaux west, north and south of Sydney. He also

was lucky to have available the skills of men such as David Lennox for bridge design and building and the military-trained George Barney, Percy Palmer, and George Mann (although Barney and Mitchell did not see eye to eye). Mitchell was responsible for the daring answer at Lapstone, i.e. cutting directly through the monoclinal structure, up a small valley, thus avoiding the problems that have dogged the builders and maintainers of later roads and railways running along the front of the steeply dipping escarpment. He was equally daring at Mt. Victoria by ignoring official orders and throwing a causeway across a narrow gap to provide a solution that continues in use to the present.

Mitchell's solution north of Sydney is no longer in use, for various reasons, but it is nevertheless also a classic one, still worthy of study. The major obstacle was the ascent from Wisemans Ferry to the Hornsby Plateau, which Mitchell attacked with typical boldness but effectively, by replacing the first ascent route surveyed by Surveyor Heneage Finch, and with a sense of proportion, building a steep, but steady grade road by cut and fill, with particular attention to drainage, and using the local Hawkesbury Sandstone. He undoubtedly made provision to protect from erosion the weathered dyke which the road crosses halfway up the ascent. Ash (1992) points out that Lieutenant Percy Palmer was also involved in this project and may have been involved in the details of construction of this fine piece of engineering construction. As mentioned earlier Mitchell's broad knowledge and his use of the Dundas igneous material as road base (and other similar material as available) ensured good results.

Later road engineers during the 19th century seem to have largely "gone it alone" as indicated by Warren (1888) and Dare (1903). Warren's very long and detailed paper contains few mentions of geological matters except for noting "a very romantic, but somewhat dangerous road has been made around the Coal Cliff", which he amplifies slightly by commenting on the need for modifications in the slopes of embankments, due to the "treacherous nature of the material excavated, and the formation of the country. Several slips of considerable magnitude have occurred in the embankments and cuttings on the Illawarra railway".

Concerning roads Warren wrote: "the [Sydney] streets with light traffic were reconstructed with satisfactory results in the following manner: a solid foundation, consisting of hand-packed hammer-dressed sandstone pitchers, ten inches deep, was laid and covered with a layer of broken basalt two and a-half inch gauge which was rolled to a smooth surface with a steam roller: the rise in the road was made one in forty. On steep grades, in which Sydney roads abounds, frequently ranging from one in nine to one in twenty two, dry Macadam stone stacked on a platform is covered with well-boiled tar and left for about five weeks before using on the road. It is spread and rolled to a smooth surface and finished by sprinkling over the surface fine screenings or sand. Later, from 1880 hardwood blocks laid on concrete were used with tar and basalt screening filling the spaces".

The Department of Public Works introduced road material testing before 1921 (Dept of Main Roads, 1976), but not till the 1950s did the Department of Main Roads take geologists into the fold as an essential part of their organisation.

Much of the history about routes and construction can be found in Upton (1932) and Department of Main Roads (1976).

The Pyrmont Bridge

The Pyrmont Swing Bridge is regarded as a classic of its kind for its engineering design. In relation to the geology encountered the paper by the designer Percy Allan (1907) notes only that five boreholes passed through 3 feet of mud and 25 feet of arenaceous clay then sandstone with a "dip of 8 feet in the diameter of the pier". Because of "the thick clay layer it was determined to sink a wrought-iron caisson to the rock by open dredging, then to pump out the water in the caisson and excavate a trench in the sloping rock sufficient to

enable the whole periphery of the cutting edge to be bedded in the solid rock". It is not made clear by this description taken from Allan's paper, but it seems likely that the clay encountered by the boreholes was indicating the presence of a weathered dyke, and that the pivot pier could have been poorly founded. The fact that piles had to be driven 78 feet through clay to support the 'rest pier' on the Sydney side of the brige supports this idea. Although not marked on Edgeworth David's "dyke map" (David, c. 1900) (Figure 6) recent work indicates a northwest trending dyke close to this position. Allan's last bridge design was Tom Ugly's road bridge, (1924-29). Here the geology finally forced itself on the engineers and it received the attention it deserved, because of the 52m of silt encountered.

Figure 6. Part of dyke map prepared by Edgeworth David (Unpublished, c 1900).

Bradfield (1913) gives a brief history of plans to bridge Sydney Harbour up to that time. The Harbour bridge thrusts its weight on two gigantic steel bearings, set in foundations of concrete, forty feet deep, embedded in solid sandstone. Although Bradfield (1932) still gives no details of tests on the bearing capacity of the founding sandstone he notes that the transfer of load through the steel and concrete base should produce a pressure on the sandstone of 200 pounds per square inch. The steelwork of the arches is supported by cables anchored 132 feet in rock in tunnels inclined at 45°. Gladesville Bridge is a later example of a single arch bridge built using the strength of the sandstone.

RAILWAYS

It was to be many years before geological advice was sought by the railway engineers, but the geologists benefited by the availability of fresh cuttings to work out stratigraphy and to examine dykes and structural features in the Sydney region. C.S. Wilkinson set an early good example, by publicising these features in the local press, and later in tourist publications sponsored by the Railways. Details of the construction of the northern line, involving some interesting geological problems, and a discussion of the interesting zig-zag from Thornleigh to the quarry of prismatic sandstone are given in Singleton (1965-66) and Branagan (1995). The major geological problems were undoubtedly with construction of the Hawkesbury Bridge.

THE HAWKESBURY BRIDGE

Because of the importance of this bridge I will review its planning and construction. When the decision was made for the route of the railway the Chief Railway engineer, John Whitton, himself designed a bridge for the Hawkesbury crossing, although there was talk of a train ferry to overcome the problem (Preston, 1983). However Whitton's proposal was rejected in favour of an international tendering process, which selected the Union Bridge Company of Brooklyn, USA, which

then sublet almost all phases of the bridge construction.

Quite good details of the construction methods for the piers are given in newspaper articles and illustrations, drawn on the spot (*Sydney Mail*, 1886, *Daily Telegraph*, 1889) (Figure 7). The method employing caissons was new, being employed almost simultaneously on two other bridges (one on the Hudson River, USA, the other on the Hooghley in India,). Three dredging tubes were placed within an outer steel caisson, which was constructed on site from sections brought by ship. As material was removed it was replaced by concrete and additional caisson rings added until firm foundations were reached. The deepest foundation proved to be the last of the piers emplaced, reaching a (then) record 169 feet. This caisson was completed in one year (May 9, 1887 -May 11, 1888). Bluestone (probably from Melbourne) formed the plinths of the piers (although Fewtrell (1949) suggests Gib microsyenite), and local Hawkesbury Sandstone the upper portions.

But what of the foundation conditions for this mighty structure? Burge (1909a) indicates that preliminary borings were made and *The Engineer* (1886) bears this out, but I have found no details of the methods employed. Burge just states that "a belt of mud" extended to a depth varying from 60 to 170 ft below HW mark, overlying sand, the greatest depth of water being 77 feet. On the other hand H.C. Russell (1885) says that a water depth of 49 feet overlay 31 feet of light mud, 87 feet of black mud, 8 feet of very hard sand, a total of 170 feet. However, sadly both statements seem to have been interpreted as providing uniform thickness and properties of each sedimentary unit across the site, a matter which proved to be far from the truth, as the builders were to find to their cost.

It is perhaps significant of engineers' attitudes of the time that W.H. Warren, Professor of Engineering at Sydney University, in his discussion of engineering progress in Australia

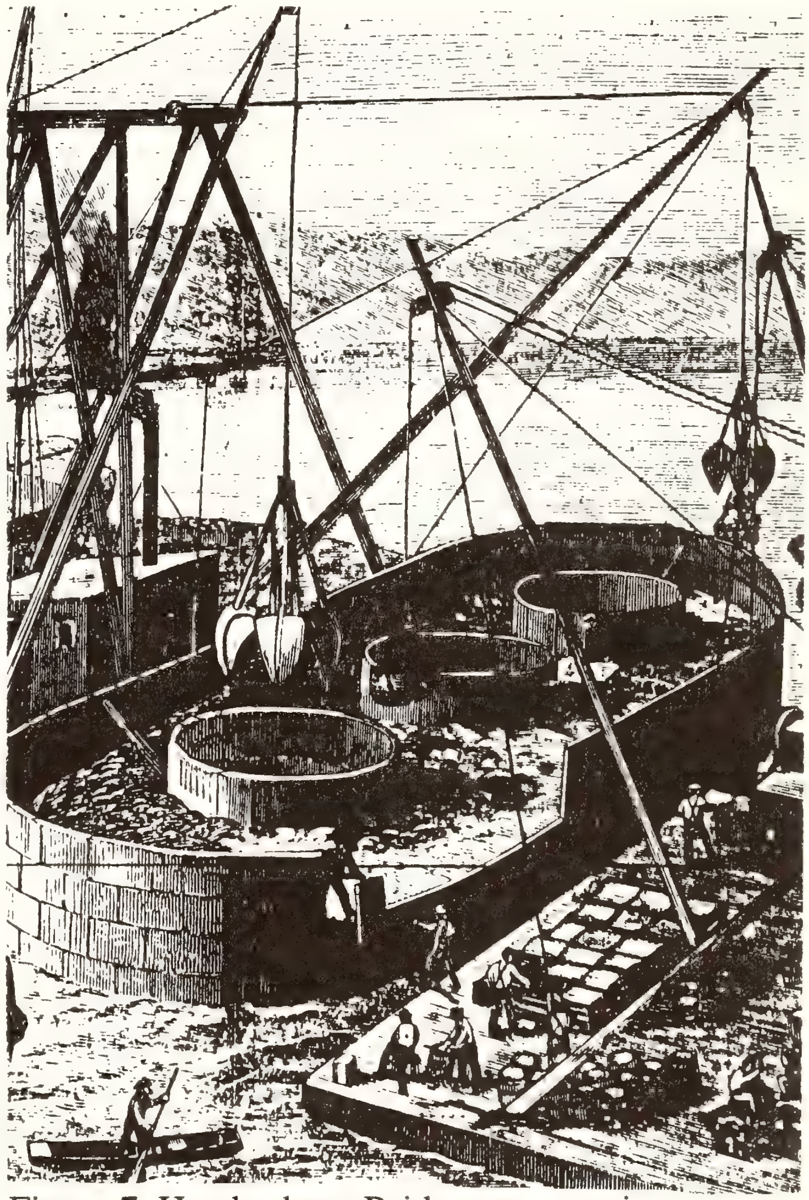


Figure 7. Hawkesbury Bridge construction.

(1888), makes no comment on the foundation conditions of the Hawkesbury Bridge, while noting that "this bridge represents in its design the combined experience of the most eminent engineers both in England and America."

It turns out there were real geological problems encountered during the bridge construction and which led ultimately to the mere fifty year life of this structure, one of the world's acclaimed engineering masterpieces of the nineteenth century. Why this bridge did not fail remains a mystery to me!

Burge (op. cit.), following his minimal discussion of the foundation conditions, describes the caissons in considerable detail, commenting on the splaying out of the dredging wells to meet the outer skin and each other in a strong cutting edge formed of heavy steel plates. The theory of placing

the caissons was straightforward. "The shoe, having been built on shore at Dangar Island, and provided with a timber false bottom was floated out to position and sunk to the bottom of the river, by removing the temporary bottom, and partially loading the caisson with concrete. The caisson was then sunk through the mud by dredging the material from the bottom of the wells and by loading the space between the wells and the skin with concrete, more steel being built up as the caisson went down."

As soon as the structure was firmly in the sand, the dredging wells were filled with concrete, and the masonry was then begun at a level somewhat below low-water. The concrete was supposed to be composed of one part of Portland cement, 3 parts of sand, and 6 parts of stone, broken to 21/2-inch gauge. The stone was what is locally known as Kiama blue stone.

The practice of the caisson sinking and concrete preparation was something else altogether from the theory. Caisson number 5, the first begun (on 9 December, 1886), gave most cause for alarm, and was the last finished (9 October, 1888). After it entered the mud it started to tilt downstream (to the east). The first method tried to correct this was to excavate the eastern well in advance of the other two, thus, in theory, causing the caisson to tilt its vertical axis towards the west. However this method did not work, even when the difference in excavation depth was more than 4m. Dredging outside the caisson was then tried, and all excavated mud was dumped on the eastern side. By the time the caisson had reached 75 ft (22m) below the river bed, the divergence was 5 ft at the base and 3 ft at the top, the axis still tilting to the east. The allowable margin for lateral divergence was 2 ft. When the caisson began to enter sand it began to move towards the vertical, but there was more lateral divergence at the top. Then the dredge grabs got into difficulties, one being permanently lost, not recoverable by divers.

The (sub) contractors, Anderson & Barr of New Jersey, then drove a series of piles on the east side to support a cribwork, which was loaded with stone and intended to prevent further movement. They put in a similar structure about 140m upstream to anchor the caisson top firmly, while further digging continued in the eastern well. However the two cribwork structures were still founded in mud, and as the sinking continued and the caisson continued to correct itself it pushed over the eastern cribwork. The caisson was now well into the sand at 144 below HW of ordinary spring tides. The next solution tried was to place an additional caisson in the form of a crescent, made of steel plates, on the western side of the original structure. Two wells for dredging were provided, the space between being loaded with concrete. However when the structure was about 28 ft from the bottom the wells caved in under the pressure of the mud on the west side and the original caisson on the east, so that further sinking was impossible, and it could not be got up either! The only solution was to begin the masonry structure at a much lower level than originally proposed (some 3.7m, 12 ft 6 in) and corbel out. A coffer dam enabled this to be done, with solid stone, (basalt or microsyenite) 7 to 8 ft in length, with a 9 inch overhang in each course, and the centre line of the western girder was situated over the centre of the masonry column. This fell within the resultant line of pressure on the pier.

The difficulty was attributed to variations in the consistency of the mud, the east side being more consistent than on the west and consequently not caving in so quickly. Part of the problem seems to have been caused by the outward splay of the bottom of the caisson. This was corrected in the later caissons Nos. 1, 2 & 3 before sinking, and they went down without significant diversion. No. 4 gave few problems, with only slight divergence from its planned position, but No. 6, sunk near the northern channel moved sideways towards the bank, and was affected by the founding on a section of mud that contained large tree trunks (David and Halligan, 1908) so that the span lengths had to be varied in this part of the bridge.

Survey measurements between 1890 and 1945 revealed progressive settlement of the piers as well as lateral movement. In May 1945, the top of pier 6 was 5&11/16 inches downstream from its correct position.

How much of the concrete was properly mixed and placed remains somewhat uncertain. Within a year of the opening of the bridge the subcontractors for cement, Burge and Barrows of Kent, were required to remove faulty material at the top of the caissons. A cofferdam built around each caisson exposed concrete of the poorest quality in each case. At No. 2 pier 15 cu yds of a mixture of sand, mud and a little cement had to be replaced. The Union Bridge Company spent 9 months replacing the faulty material. In 1937 inspection by divers revealed extensive rusting of caisson 4; furthermore the concrete inside could be easily penetrated by pushing a rod into it, and the other piers showed similar weakness.

Between June 1937 and August 1938 cracks in the masonry of No. 4 pier alerted engineers to the need for a careful investigation of the piers below water level, using a diver and sinking a shaft inside a cofferdam and boring tests inside the caisson. It turned out that some of the pier problems were the result of a push and pull action because of virtually inoperative expansion bearings. Cracks in No. 1 pier, inactive since 1938, extended rapidly in August 1945.

It is interesting that the bridge specifications did not give a limiting foundation pressure, which led to very different tenders for the foundation costs. This lack of tight specification was perhaps the major weakness in the bridge design, as opposed to the extraordinary details specified for the superstructure.

C.O. Burge (1909b) has a nice finish to his story of the Hawkesbury River Bridge: "The bridge was opened by the Governor of the colony, Lord Carrington, in the presence of eight hundred guests from all the colonies, and in an inevitable banquet that followed, speeches went to buttering, on both sides, politicians whose share in the work was infinitesimal, and never mentioning those who had anything to do with its construction. A stranger hearing them might think that the bridge was ready made like Venus from the froth of the sea, that it required as little preparation for the work as supposed necessary for the duties of a Member of Parliament."

QUAYS AND DOCKS

Circular Quay

The portion of Sydney popularly referred to as Circular Quay hides what Stephenson and Kennedy (1980) call "the biggest and most enduring engineering construction" of early Sydney" and "one of the biggest enterprises of foreshore reclamation [ten acres] in the world at that time". This area which should perhaps be correctly called semi-circular Quay, was an original triangular shape with its tidal limit about Bridge Street. The plan was designed and supervised by George Barney, requiring a waterline 2 500 feet long with a depth of 20 feet to accommodate 20 average size vessels. It involved the conversion of the Tank Stream to a sewer, and required importing a dredger, two punts, two diving bells and a light railway system (Sutton, 1992). Convict labour used sandstone from the Argyle Cut quarries to the west, the Tarpeian rock to the east and from Cockatoo Island to fill the area on the east side of the Tank Stream, leaving the deep water section available for limited navigation to Bridge Street. This work, begun in 1837, was completed by 1844, the last and largest work by convict labour in the Colony. During the construction of the Cahill Expressway in the 1950s the Quay became a rectangular one.

Moves for a similar semi-circular quay in Woolloomooloo Bay were set in place in the 1850s, Thomas Mitchell being involved in ensuring public access and the reservation of streets as various private individuals attempted to manoeuvre for privileged shoreline control. Sandstone blocks were readily available to supply the walls of this structure.

Docks

The constant demand for building materials saw many quarry sites in the inner city area, and islands in the harbour were not immune. Goat Island, for example, was quarried for building stone and rubble, to such an extent that Thomas Mitchell complained in 1831 that the island was in danger of being quarried away. There was discussion on the possible use of the island for a dock. However in 1854 Mort's dock was begun in Balmain. It was a difficult pick and shovel excavation; 400 feet long by 50 feet wide, and later enlarged. On Cockatoo Island twenty feet deep "bottles" were cut in the solid sandstone about 1840. This stone was quarried and used to fill Circular Quay. In 1851 a large graving dock was completed on the east side. A larger dock was built on the west side between 1884 and 1890. The earlier dock was designed and built by G. K. Mann, who had worked under George Barney. Mann tested the strength of the sandstone to calculate the amount of gunpowder needed, and in 1848 blasted away in one explosion the cliff covering the dock site avoiding fragmentation. During extension of the eastern dock in the 1860s a Labyrinthodont was discovered, which caused considerable interest among geologists (Stephens 1886a & b).

In this century we have seen several large harbour projects that have involved geology. Helffenstein (1952) discusses the construction of the Garden Island dockyard, commenced in 1945 for the Navy by the Water Board (Beasley, op. cit.).

The Botany Bay project, an environmental project begun in 1972, set out to assess the impact of human settlement on a "typical" coastal environment. There had been many changes in the almost two hundred years since European activity. The construction of coastal barriers along the western side of the bay had been studied by Andrews (1912 & 1916) and later by Goodwin (1971) and others. The changes to Cooks River during the initial construction of Kingsford-Smith Aerodrome, and the more extensive changes during the construction of the runways into the bay, followed by the construction of a research laboratory, were major examples of the interaction of engineering and geology, but geologists were involved generally too little, and often too late. Many of the structures were designed and constructed prior to essential knowledge of the wave and wind conditions they were designed to protect against. The massive seawall built to protect the new port facilities was begun in 1974 and by this time there was considerable consultation and co-operation between geologists and engineers.

DAMS

The need for dams became evident early, and P.E. Strzelecki (1845) was one of the first to recommend a dam on the Warragamba River. Thomas Woore, in 1867, was enthusiastic for such an edifice, and provided drawings for a large earth/rock fill structure (Figure 8), which probably would have failed, and which was well beyond the capacity of the colony at the time.

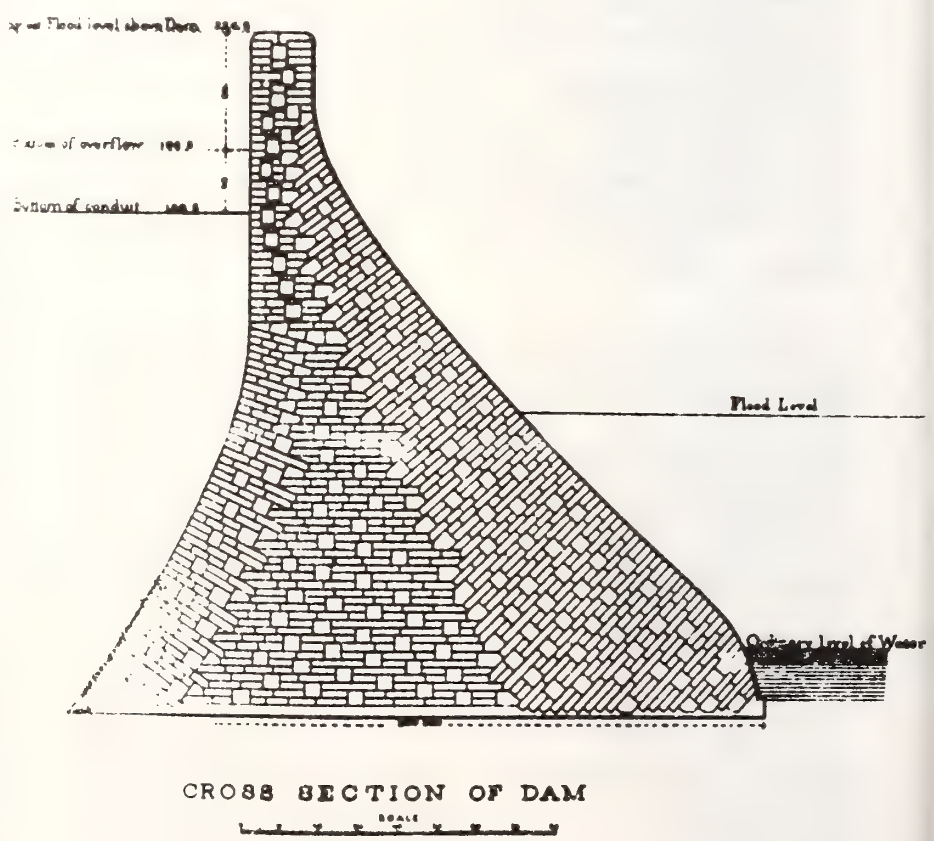


Figure 8. Warragamba Dam design by T. Woore (1867).

When Rev. W.B. Clarke gave evidence on the need for a good water supply for Parramatta in 1849 he recommended a damsite at North Rocks, which he believed "could supply the whole county of Cumberland for the next century". Despite this somewhat over-enthusiastic optimism, the site was adopted shortly after, and Lieutenant Percy Simpson was commissioned to prepare plans for a "circular dam" (Ash, 1992). This was an extraordinary decision in a way, as few arch dams had ever been built, and at the time only one modern arch structure was in planning and construction (in France). The original height of the dam, built on Hunt's Creek and completed in 1856, was 41 feet. It was built of masonry in Roman cement, and raised to 52 feet in 1898, using concrete. Ash (op. cit.) has photos of the dam and Wade (1909) describes it in some detail.

The construction of Prospect Dam in 1888 has been well-documented (Henry, op. cit.), but a probably apocryphal story persists of employing for compaction the prototype of the sheepfoot roller, a flock of sheep driven back and forth. The real story seems to be that a very large roller, made of basalt, and brought overland from Ballarat by William Pincott, was used, pulled by a team of bullocks. The northern abutment was fortuitously supplied by the edge of the Prospect intrusion, the southern by a sandstone ridge within the Wianamatta Group.

Warren (1888) gives details of the construction of the Prospect reservoir noting "the puddle wall is carried 6 feet below the solid shale, eight feet wide at the top, protected on each side by red and white clay rammed in layers 6 inches thick, the water slope is pitched with diorite blocks eighteen inches deep". It seems certain that Warren is referring to Prospect dolerite as the rock used.

This dam, painted by Arthur Streeton in 1895, was the storage dam for water pumped from the Cataract system, the site being chosen by engineer Edward Moriarty. A sizable dam was built on Curl Curl Creek, Manly Vale, in 1892 to supply Manly and Warringah, but this had to be supplemented by water from the metropolitan system in 1906, and the dam was enlarged three times up to 1922. It was replaced by the metropolitan system in 1924, but was used for ten months in 1942 near the end of a seven year drought. More recently the dam became the supply for several hydraulic research laboratories for the Water Board and the University of New South Wales, investigating aspects of flooding of the Hunter Valley, the offshore sewage tunnels, designs for enlarging Warragamba Dam, and hydraulic drawdown in large wells among others.

From early in this century, as dams became popular, engineers of the Water Board adopted as their preferred dam type in the Sydney region, concrete cyclopean masonry gravity, but slightly curved to add strength by using the abutments to some extent to take part of the load. These dams were preferred to the buttress type as built at the Junction Reefs Mine, near Mandurama, or rock or earth fill types. According to Coltheart and Fraser (1987), they were all designed by Ernest de Burgh, who in 1904 visited England and France to study dam construction and water supply. The design of these dams was strongly influenced by theoretical calculations of the American engineer Edward Wegmann. It was found, in later years, that the structures were too light, and likely to be affected by uplift and overturning, and all had to be strengthened.

As far as I have been able to ascertain the early dam design and construction work in the region was done without any geological advice. There seems to have been little or no consultation with geologists during the construction of the Cataract (1903-7) (but see below), and the Cordeaux (1926) dams, (the latter attracting 600 aldermen, few engineers and fewer geologists to its official opening).

THE CATARACT DAM

One reason for the construction of the large Cataract Dam (Figure 9) early in the century was that the low-level structure built there in the 1880s

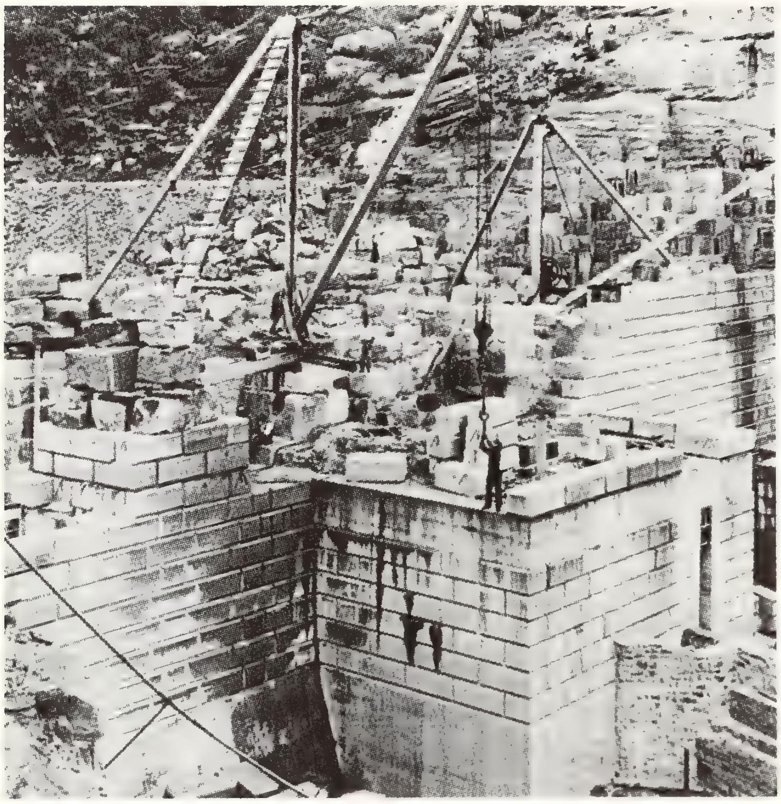


Figure 9. Cataract Dam. Masonry blocks being placed (Courtesy Water Board).

was proving inadequate. The Prospect reservoir could not be lowered too much as parts of the wall were unstable when the drawdown was high, and this was beginning to happen quite frequently as demand for water rose and there was insufficient supply from Cataract. In fact there were a number of small failures of the wall at Prospect in 1888 and the toe was weighted several times with stone. News of these failures again brought pressure on Moriarty, and he was not helped by media agitation alleging unsafe tunnels in the Upper Nepean work. Moriarty had insisted these tunnels not be bricked and that they would stand up unsupported. Some timbering had been used by the contractors where the roof was in shale. In fact they proved satisfactory, with few rock falls, and opposition to the general Nepean-Prospect scheme gradually abated (Keele, 1908).

L.A. Wade's paper "Concrete and masonry dam construction in New South Wales" presented in London in 1909 caused considerable discussion. There had been few large dams anywhere built in sandstone country to that time. The President of the Institution of Civil Engineers, J.C. Inglis, commented that it was "particularly gratifying to get papers of this kind from Colonial members". He thought it dealt with a "work of a courageous character", while Mr. C.E. Jones felt that "fears were aroused....a dangerous point had been reached in the construction of dams for impounding water.... Australian engineers must be suffering many sleepless nights, hoping their dams would not fail".

Beginning with a brief discussion of earlier dams, including those of Parramatta and Picton, Wade drew attention to the geology of the foundations, commenting that granite conditions were usually the best. However most of the paper is devoted to the Cataract Dam. Wade discussed the qualities of the sandstone, and the testing of a large block for its expansion/contraction when wet. He commented that the readily available Hawkesbury Sandstone was satisfactory in large blocks "if carefully quarried from selected layers and disposed in the work to be free from the influences of weathering". He also noted "The Hawkesbury sandstones are intersected by numerous basaltic dikes, which are in the majority of cases so decomposed as to be unfit for use as concrete, but in all cases the sandstone walls enclosing them are more or less vitrified by the heat of the basalt flow, and afford in limited quantities an excellent material for such a purpose". However, the normal sandstone was not satisfactory for use in the concrete and its use was specifically forbidden in the specifications. Basalt for the concrete was quarried from a dyke about six and a half miles from the dam site.

T.W. Keele, a fellow Colonial, was critical of much of the construction (costs), and particularly the lack of a cut-off wall upstream of the dam, needed, he felt, because of "the uncertain and treacherous formation" [of the Hawkesbury Sandstone]. Keele referred to the failure of the Broughton's pass weir in 1897 (because of air entrapment between blocks). Mr. Mattern "considered a careful examination of the rock foundation in regard to its soundness and its suitability for supporting a high dam, as well as the testing of the watertightness of the site of the reservoir, to be one of the most important

conditions for the construction of a solid and stable dam. For this purpose wide experience was necessary, and the engineer and the geologist must work together, the engineer however, having the controlling hand". In answering these comments Wade made no mention of Mattern's call for geology/engineering interaction.

Although there seems to have been no specific consultation with geologists about the actual damsite, the Government Geologist at the time E.F. Pittman, and the Chief Inspector of Mines A.A. Atkinson, were called in to examine the situation from the point of view of preventing sterilisation of the coal underlying the dam and reservoir. E. Wegmann, the American designer, commented on a number of aspects, particularly the pressures to be imposed by the dam.

L.F. Harper (then Government Geologist) was involved in advising for the Nepean (1925), Avon (1927) and Woronora dams (1927-1941). At the Nepean site he was called in when faulting was suspected, while in the Avon case he duly impressed the engineers by predicting the exact depth at which the Narrabeen shales would be encountered. At Woronora there were some very loose "sand" layers within the Hawkesbury Sandstone, but Harper seems to have been convinced that this unit was quite strong, and that there were few problems of any magnitude to be encountered. Nevertheless several significant changes were made in the Nepean and Woronora Dams with the introduction of thrust trenches at the toe and modification of the grout patterns and cutoff trenches. Although Harper's work was not extensive it probably marks the first real involvement by a geologist in large-scale engineering works in the Sydney region. Harper (1930) was also apparently the first geologist to publish in the Australian engineering literature on geological problems for dam builders.

Figure 10. Calyx cores, Warragamba Dam.

WARRAGAMBA DAM

Despite the earlier proposals by Strzelecki and Woore in the 19th century and recommendations by E.M. de Burgh in 1908 for a dam on the Warragamba, not till 1918 was there a more specific proposal, again by de Burgh who submitted a design and an estimate of cost (Coltheart and Fraser, op. cit.). The following year L. F. Harper selected a site for the proposed dam after a hasty reconnaissance. Probably for economic reasons, and the state's involvement in the construction of the Burrinjuck Dam, the Warragamba scheme only began to be considered seriously just prior to World War II.

The Warragamba Dam story from here on forms an important part of the story of interaction between Geologists and Engineers. Harper's 1919 choice of a site was the best topographical position in the valley, but drilling tests later were to show that it was not suitable for the large dam proposed. An Emergency Scheme was constructed there between 1937 and 1941 as a long drought reduced the Sydney dams to 12.5% of capacity by 1942. When the project finally took off in 1944 L.L. Waterhouse of the University of Sydney was invited to act as consultant. He, in turn, invited W.R. Browne to work with him, which they did for the next two years, being involved in the drilling which progressively moved the site upstream to avoid weak shale breccia layers in the foundations. Browne had advised on the Hume Reservoir site in the 1930s, his advice on such

matters having been largely forgotten by those who regard him as essentially a petrologist. For some reason Waterhouse was unable to continue in 1946 and Browne took over as sole geological consultant, but with the assistance of a young graduate, D. Moye, who was to gain considerable fame later for his work on the Snowy Mountains Scheme. Moye cut his engineering geology teeth on this project, working with Browne and Waterhouse, but employed by the Board. In the next four years there was a disciplined application of geology, which was clearly of significance in the design and construction of the dam. Fault and joint zones were recognised, unstable marcasite was found in foundation sandstones, and other conditions were found to be variable. Fortunately the Water Board realized the need to have its own geologists to work on the day-to-day problems of the dam construction, and W. Johnson continued this task from 1950 to 1955 (Waterhouse et al, 1951; Johnson, 1960). The problems faced during the construction of Warragamba were considerable, and the job attracted widespread attention among the engineering fraternity worldwide. It was completed in 1960.

T.B. Nicol's 1964 paper on the building of the dam, like Wade's fifty years earlier, was delivered in London and caused much discussion among engineers. H.G. Sweet (1965) added information based on monitoring of the structure, as did the engineer W.I.S. Moyes (1964). Significant matters were: 1). Conspicuous rock movements had occurred during construction, which could be attributed to changes in loads on the foundation rocks (with relatively low modulus of elasticity). 2). Stratification of the sedimentary rocks was a controlling factor in the magnitude and direction of the rock movements. Uplift of foundation strata downstream and in the abutments could be attributed to the reaction resulting from the depression of the strata beneath the centre of the dam. 3). Rock movements had probably occurred in the vicinity of the dam before construction started, and evidence was accumulating that there were some small but measurable oscillatory horizontal and vertical movements still taking place. These were attributed to regional flexure occurring independently of the elastic readjustment of the foundation rock near the dam. Further careful measurements were necessary to identify the type of movements occurring and to bring about an understanding of their causes.

In discussion H.H. Thomas asked if seismic risk was taken into account in the Warragamba design. J.K. Hunter warned about the problems of estimation of design floods. He also noted that the actual stresses in many existing dams were different from those assumed when built. Their survival was due in part to being small by present standards and the margins of strength inherent in the materials were large. R.C.S. Walters asked why were rock-fill or earth embankments ruled out [they would have been 350 ft high]. Nicol replied that the dam was designed because of the success of the previous gravity dams in the Sydney region (although some problems were already emerging), and there were no precedents for high rock fill dams using sandstone of the quality available near the site. Moreover floodwaters were more easily disposed of over a concrete dam. He pointed out that jointing in the abutment walls prevented an arch dam, and that no specific allowances were made for earthquakes in the design (although this was certainly taken into account in later modifications of the dam).

Nicol's reply [Item 311] noted that careful measurements of rock movements would continue for a long time and commented that there was already evidence that in at least some part of the world there was significant horizontal compression in the earth's crust. This somewhat throwaway comment was to prove of considerable significance to engineers in the Sydney region in later years. Moyes (op. cit.) developed these ideas.

More recently attention has centred on "disaster" aspects of the Warragamba dam, the consequences of a "hundred-year" flood or "probable Maximum Flood" 2.5 times the largest flood ever recorded in 1867, on both the structure and the downstream region. Consequently the dam

was raised and strengthened through post-tensioning between 1987 and 1989. Plans have been drawn up for a new auxiliary spillway, to be followed sometime after 2000 by a larger rock-fill structure, not dissimilar to that proposed almost 150 years ago by Thomas Woore, but technically somewhat better designed!

Not until 1980 was a large rock dam (Mangrove Creek) constructed in the Sydney region using local (Narrabeen Group) sandstone as its main component. There were inevitably a few problems at the Mangrove site, not least the degree of wetness which would achieve best compaction during rolling. There was also some movement caused by stress relief during excavation.

TUNNELS

"There are not many opportunities for the enjoyment of novel sensations in Sydney, life is very humdrum" wrote a reporter for the *Sydney Morning Herald* in 1887 . . . "[the thrill-seeker] can do nothing better than descend into the Bondi Sewer, where novelty of a peculiarly invigorating kind may be very easily and effectually obtained...he will arm himself with the necessary permission and wend his way to one of the shafts situated at certain points in the city, which dive down into the bowels of the earth some hundred feet or more to the level of the tunnel. That at the intersection of Liverpool and Oxford Streets affords ample opportunities for arriving at the true beauties of the tunnel....having arrived he will provide himself with a candle, ascend 12 feet to a platform from where he is lowered in a bucket (liberally coated with wet clay), amidst the enthusiastic applause of one small boy without boots". He added "[the tunnel is]....the greatest sand-drive in the world, it is absolutely flawless...the magnitude of the project absolutely flawless. The outlet is at Merriverri cliffs....One of Nature's altars". The sand tunnelling mentioned was in fact largely a cut and cover for that portion of the work which extended through the sand dunes which formerly existed in the vicinity of Blair Street, Bondi, and not unlike the proposal put forward by Thomas Woore in 1872.

G. Mansfield (1898) in somewhat triumphalist fashion praised the efforts of the engineers: "this tunnel was the result of a desire to remove sewage from flowing into the harbour, which had been the 'easy' solution in earlier years". Thus the Government developed a "system of sewerage, constructed upon the most approved methods of modern science, and which in its full development will challenge comparison as a triumph of engineering skill with that of any city in the world".

A few railway tunnels were in process of being cut in the Sydney region about this time, including the very long Woy-Woy tunnel (Branagan, 1995), but discussion of these is outside the scope of the present paper.

A HARBOUR TUNNEL?

Crossing Sydney Harbour by means of tunnels was seriously considered by engineers as early as 1885, when F.B. Gipps and C. O'Neill (who devoted his spare time to forming the St. Vincent de Paul Society in Australia) designed a tunnel. In the same year pipes were laid across the harbour to carry water to the North Shore. These were tested by driving out the salt water and replacing it with fresh. This was the year when Henry Parkes won the seat of St Leonards with the catch-cry "Now who will stand at my right hand and build the bridge with me?" as there had been agitation to build a bridge to mark the centenary of European settlement and John Whitton the previous year proposed a suspension bridge across Sydney Harbour. Gipps consulted for the Harbour Tunnels Company in 1887, tunnels being planned for both railway and vehicular traffic, at an estimated cost of £450 000, and with at least 30 feet of solid rock between the crown and the harbour floor. Gipps (1887) undertook a series of borings between Fort Macquarie Point and Beulah Street, and between Dawes Point and Milsons Point to "find the character of the supposed rocky bottom" on the

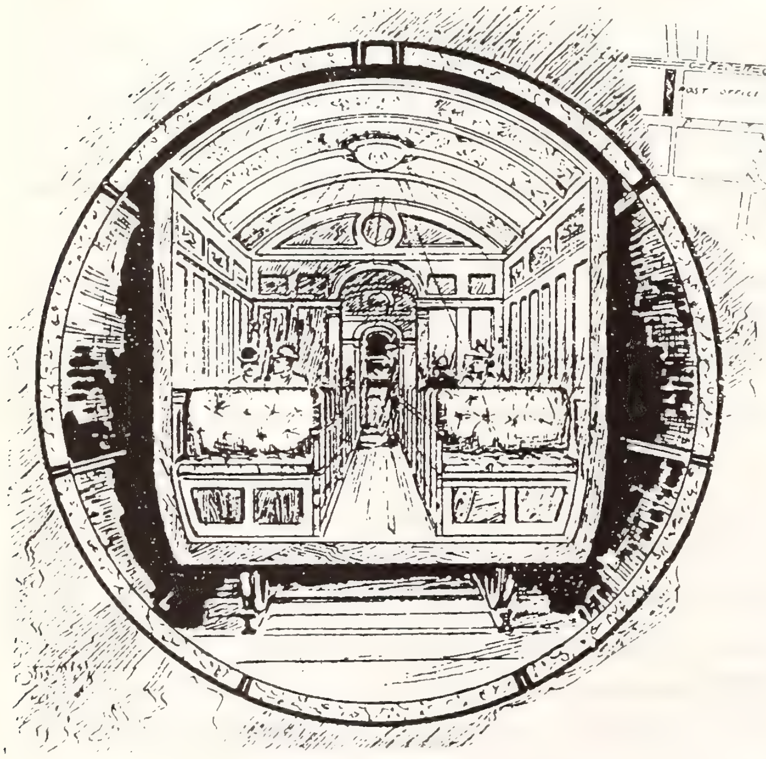
lines of the proposed tunnels. He was more than a little surprised that the Government charts were misleading, as the sounding rod indicated a minimum thickness of 44 feet of silt, and a maximum of 64 feet. Although there was more than 63 feet of silt at Dawes Point, the greatest amount of silt occurred at Fort Macquarie, and he pondered whether this was the result of accumulation from city drainage, this point being the principal outlet for city sewage from the 1850s to the mid 1880s. The increased gradient, if the tunnel was to remain in rock, was one of the reasons for abandoning the scheme at that time.

However the idea of a harbour tunnel did not die with this realisation of the irregularity of the rock floor. J.H. Maiden (1897) refers to the activities of a select committee at that time considering a double tramway track to North Sydney requiring some 11/4 miles of tunnel. There were in fact proposals at this time for separate rail and road tunnels (Figure 10), with provision for a partially cut tunnel in rock and an iron "pipe" driven through the soft alluvium, a solution that did not greatly differ from the road tunnel finally constructed in 1990. Bradfield (1913) and Stephenson and Kennedy (1980) note that a 1908-9 committee recommended that two tunnels, one for railway, one for road, be built under the harbour, with a subway under the city. However sceptics still considered the tunnels would flood or cave in.

Bradfield (1913) compared crossing the harbour by bridge and tunnel, but devoted only a little attention to the water depth, and made no comment on the geological variation under the water, but, of course, his major interest was in a bridge crossing.

The harbour was finally first crossed by a tunnel, but of considerably reduced dimensions, built between 1913 and 1922 from Long Nose Point to Manns Point, Greenwich for electricity cables. Dargan (1992) discusses the problems encountered during this pioneer work, which cut through a weathered dyke, and much weak rock. The tunnel continues, I believe, to attract intrepid divers.

The rate of change in attitudes and achievements can be seen in the opening of the Harbour Tunnel in 1994. Sydney newspapers of the 1970s and 80s indicate conflicting opinions about sites and methods of achieving satisfactory results. Hawley (1972) discusses a pefabricated tunnel proposal, while the Stekete (1982) featured



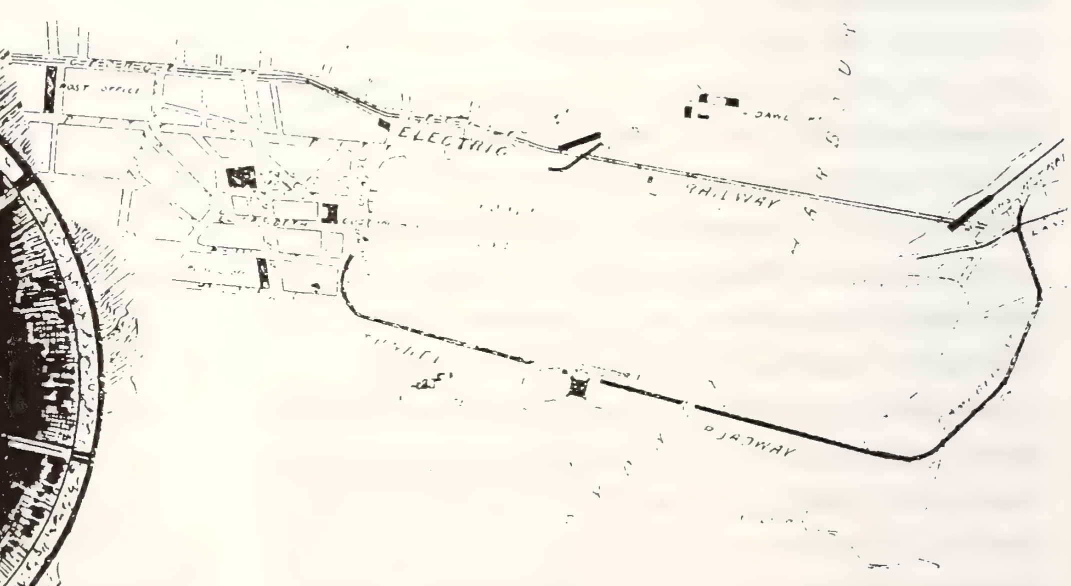


Figure 11. Sydney Harbour Tunnel Plans (1897).

a combined tunnel and bridge (between Greenwich and Birchgrove) proposal supported by the Department of Main Roads, although two years earlier *City Express* (1980) was remarked gloomily that Sydney would "have to wait until after the year 2000 before it gets moving on a second harbour crossing".

THE PRESSURE TUNNEL

One of the most significant tunnels in the Sydney region was the Pressure Tunnel built by the Water Board in the 1920s from Potts Hill Reservoir to Waterloo Pumping Station (10 miles), approved by the Board in 1915, and approved by a special panel of experts in 1919 as two cylindrical tubes in one heading, at a cost of £1 000 000. It was later amended to a single 10 foot tunnel. Trial bores were put down during 1921-2 followed by the sinking of 17 shafts. This tunnel was to be an essential part of the city's water supply for many years. It was expected to withstand the pressure of water pumped through it merely by the rock cover and a thin concrete lining. Virtually as it was being tested over a distance of two and a half miles miles (May 1930) it failed over a length of 700 feet where it had passed through a dyke and weak rock. In fact cracks had been observed in the concrete lining prior to testing. A Royal Commission was held over this structure between November 1932 and May 1933 when engineer D.G. Bruce gave evidence that the failures were "due to bad ground, others to insufficiency of cover". He felt that some apparently safe sections might fail in "18 months or two years". The Commission attributed the failure to incorrect design and location, but agreed that the recommended remedial measures (by placing an impervious steel lining within) were adequate, but at a cost of £2 886 000! No geologists seem to have been involved in the enquiries associated with this tunnel, which at the time was one of the largest pressure tunnels ever built (Haskins 1931-32). A second tunnel was begun in 1946 at depths between 15 and 65 metres. Of the 16 kms 8 were driven through sandstone, 7 kms through shale and 1 km through a mixture of sandstone and shale.

Braybrooke (1985) has summarised the history of tunnel construction in the region, prior to the time of the successful completion of the three offshore tunnels for the Sydney Water Board, as it then was.

OFFSHORE TUNNELS PROJECT

The recent and much-maligned Offshore Tunnels project of the former Sydney Water Board is an impressive example of co-operation between engineers and geologists, particularly within the Principal's organisation, but also with the contractors. These offshore tunnels might be regarded as the end-point of a system which was built up over more than 150 years for the disposal of Sydney's sewage, having in 1888 diverted the disposal from the previously happily-accepted method of running pipes into the harbour, which began in the 1850s. Whether the future will see a continuance of the present method, retreatment of sewage water or a move to local more efficient sewage farms or other more environmentally friendly methods remains to be seen (Beder, 1989).

The Water Board decided on the offshore tunnel option in 1980 and ten years later had completed the project with the minimum of fuss. There was a constant exchange of information between the engineers and geologists, the project getting under way with a considerable amount of drilling on and offshore. Laboratory tests suggested that some of the claystones would not stand up for long during tunnelling, but geologists argued that the material en masse, and remaining damp, would behave quite well in the tunnels, a contention that proved correct, and which had been earlier substantiated in the construction of the Kincumber Tunnel, McNally (1980). Engineering geological logging was carried out almost continuously through the tunnels at a scale of 1:200.

Contractors for the offshore tunnels tended initially to reject geological advice that horizontal

stresses could cause difficulties during initiation of tunnelling, but soon learnt that such could occur! On the other hand geologists' fears that the intersection of tunnels with dykes not far below sea level at Bondi and at North Head might result in inundation by sea-water proved negative. Other dykes encountered offshore in the North Head Tunnel were assessed well ahead of time by long-hole probing. One final aspect of the project was tunnel at Epping on the M4 expressway (Allison, 1995) and serious plans for other tunnels in the central business district. More ambitious schemes have been discussed by others (Baggs, 1994; Totaro, 1996, Lewis, 1996). It is worth noting that the architect/engineer Florence Taylor (1920) was well before her time in advocating tunnels to relieve Sydney's traffic congestion (Loder, 1989).

Figure 12. City Railway construction 1920s. Note inclined jointing controlling rock breakage.

the need to monitor the tunnels for the possible influx of methane gas. Several significant inflows (derived from the closely underlying coal measures) were recorded late in the project. Aspects of the geology of this impressive project have been discussed by Hawkins and Thomas (1993), Lowe and McQueen (1990): the engineering aspects by Clancy (1980), Henderson (1990) and other Water Board engineers.

More recently there has been an increased interest in using the underground in Sydney, with a number of pedestrian tunnels, a particularly significant parking station for the Sydney Opera House using a double helix design, a large road

STABILITY OF STRUCTURES

Little attention seems to have been given to structural defects in the local rocks prior to the 1970s. This was largely the result of the "soft-rock" methods of heavy support employed in tunnelling, and the generally slow rates and limited depth of excavation for building foundations, which allowed adjustments in rock faces to go largely unobserved. Branagan (1969) pays little attention to faulting and jointing, but work in the next decade showed that these structures were quite significant. Branagan (1977, 1985), Norman and Branagan (1984), Branagan et al (1988), Mills et al (1989), Mills and Branagan (1990), Branagan

(1991) deal with a range of structural defects that have caused problems in the Sydney region. Some of the close-spaced shear zones noted by Norman and Branagan (op. cit.) caused difficulties during the construction of the city railway in the 1920s (Fraser,1930; Humphries, 1931), but sadly these were never mapped or followed up at the time and their intersections during later constructions in the city area usually caught engineers unprepared and their treatment caused additional delays and added costs on numerous sites.

Experience gained on the Warragamba project and the Snowy Mountain Scheme was important in beginning to understand the existence of relatively high horizontal stress, which was recognised in the Sydney district by David Jordan during examination of the Kings Cross and Martin Place Stations on the Eastern Suburbs Railway. The problems such stress and its relief could cause began to be recognised in a variety of large building sites, such as the present Stock Exchange, World Square and the ANA Hotel , the latter two both being adjacent to railway tunnels and which required special support treatment (Pells, 1990, Baxter and Nye, 1990). At times there have even been explosive failures of cliff faces, probably caused by the relief of such stress, as at Northbridge and Woronora (Branagan, 1985).

REVIEW

By the 1970s co-operation between geologists and engineers was fairly well-established in the Sydney region, brought together by a realisation that there was economic value in working together. Technical knowledge was spread by meetings and publications of the Australian Geomechanics Society (formed 1970) and the Engineering Geology Specialists Group of the Geological Society of Australia (formed 1979). As a result McMahon et al (1975) set out the first engineering classification of sedimentary rocks for the Sydney area based largely on Moye's classification developed on the Snowy Mountains Scheme (Moye, 1960), but adapted for sedimentary rocks.

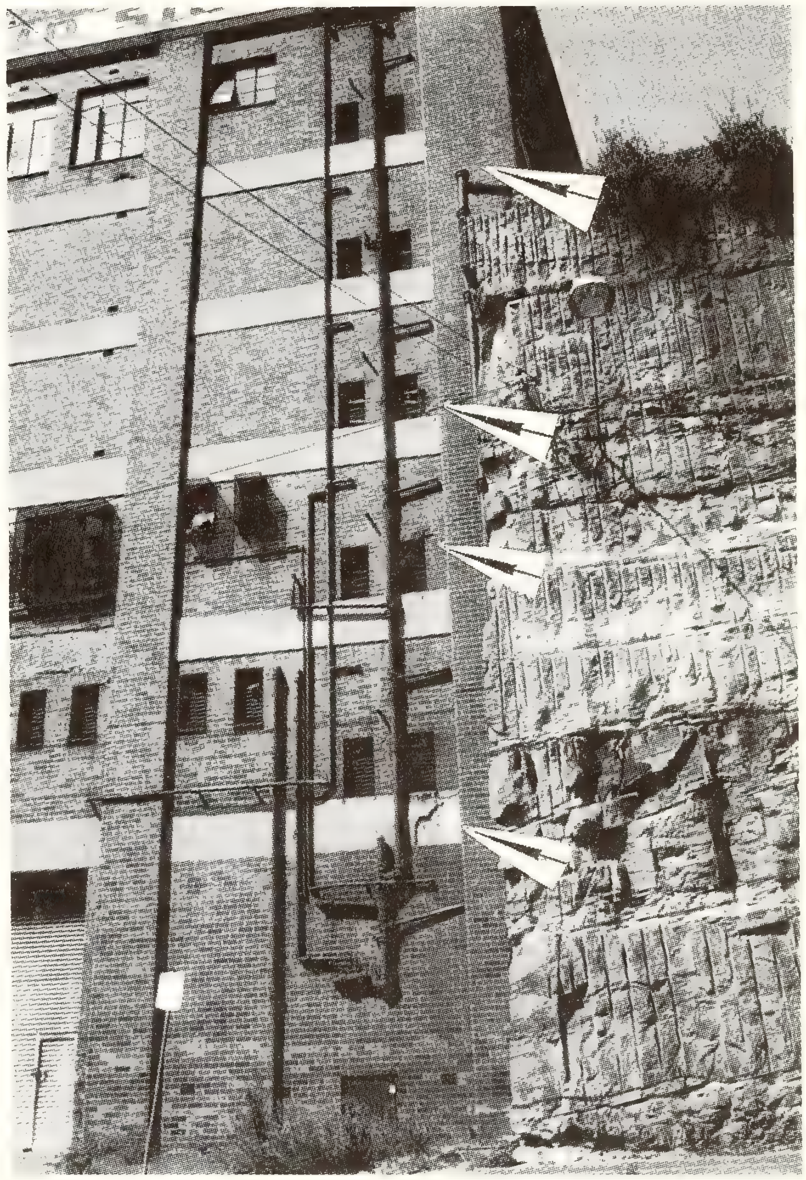


Figure 13. Failure of wall at Pyrmont due to horizontal stress from adjacent sandstone.

Burgess (1977) also pointed out that only in the mid-1960s were the effects of geological conditions given much consideration by engineers. He discusses the problems encountered during construction of a telephone exchange building in Hay Street, due to the late identification of a wide weathered dyke. Similar problems were also discussed by Branagan (1969) and Rodway (1985). These papers highlighted the continuing lack of a systematic approach to recording sites of potential weakness, and continuance of out-of-date building codes, (e.g. shale bearing-capacity values) which professionals needed to overcome through organisation and new standards. There was co-operative research on the use of crushed sandstone as aggregate, lime stabilisation of picrite and breccia, tunnel boring of Hawkesbury Sandstone, which has led to many changes. The acceptance of Burgess's predictions have taken place to some

extent (mapping at scale, crushed sandstone, recording weak spots, revision of codes).

Engineers learned to their cost that numbers alone do not supply all the answers. One can cite the Pressure Tunnels problems of the 1920s, the earlier Hawkesbury Bridge, laboratory tests for the offshore tunnels, and the Sydney floods of 1984 as just a few examples.

Pells (1985) brought together much of the recent information and approach to engineering geology in the Sydney region which had developed in the previous twenty years.

In the introduction I mentioned I had earlier (Branagan, 1972b) attempted a quantitative rating of geological conditions in relation to engineering requirements in the Sydney region. A somewhat different approach was taken by Burgess (1974) in applying a numerical approach to the particulars of site conditions, and which built on the earlier classifications of Moye (1960) and others. The cynical amongst the engineers might regard these numbers games as attempts by geologists to win back the lost ground of geomechanics which was largely taken over by engineers in the 1960s. While this may be so we must not lose sight of the essential qualitative and even intuitive nature of much geological work, which can stand quite proudly alongside the equally essential quantitative work of the engineer.

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RECENT DEVELOPMENTS IN PLANETARY RESEARCH

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ABSTRACT. Our ideas about the origin and evolution of the solar system have advanced significantly as a result of the past 25 years of space exploration. The paper begins with an assessment of the problems of building the giant gaseous planets. The role of meteoritic, asteroidal and planetesimal impacts, and of the importance of random events is emphasised. Other topics include the reasons for the existence of the asteroid belt, and the small sizes of Mars and Mercury. A discussion is given of the Moon and Mars, including the problems in forming our unique satellite, the Moon. The geology of Venus, once thought to be a twin of the Earth, has revealed startling differences in tectonic and igneous activity, now revealed by the Magellan Mission. Since it is so difficult to form a clone of the Earth in our own solar system, the chances finding one in another planetary system seems highly improbable because of the large number of chance events involved. The importance of asteroidal impacts is emphasised by a discussion of the massive impact on the Earth at the end of the Cretaceous Period, that has provided a possible new explanation for the extinction of at least 70% of species living at that time, including all of the dinosaurs and the giant marine reptiles. The dominance of the mammals and the emergence of Homo sapiens is due to such a chance event.

"Since one of the most wondrous and noble questions in Nature is whether there is one world or many, a question that the human mind desires to understand per se, it seems desirable for us to inquire about it." (Albertus Magnus, 1200-1280 A.D.)

THE SOLAR NEBULA

The solar nebula formed about 4670 m.y. ago, in a universe that would look quite familiar to us and which had already existed for at least twice as long. This mass of gas and dust became detached from a larger molecular cloud in a spiral arm of the Milky Way galaxy and collapsed under gravitational attraction into a disk. If the disk had been larger or spinning more rapidly, a double star system (these constitute about 80% of all stars) would have formed instead of a single star and neither the planets nor ourselves would exist.

The composition of the solar nebula is well understood. It comprised 98% "gas" (71% H, 27% He), 1.5% "ices" (mostly water, with methane and ammonia) and 0.25% other elements usually referred to as "rock". The amount of "rock" is so small that it could be ignored to a first approximation, except that we are standing on some of it.

Due to the fortunate coincidence between the composition of CI meteorites and that of the Sun, as recorded in the photospheric spectra, we are very well informed about the composition of the "rock" for nearly all the elements in the Periodic Table (Taylor, 1992, Table 2.15.1). As the disk contracted, mass flowed inwards, the Sun formed in the centre and angular momentum (spin) was transferred outwards, so that the planets are spinning much faster than the Sun. Probably the disk was non-axisymmetric, a condition which would allow both the inward flow of mass and the outward transfer of angular momentum (Boss, 1988). Small, metre to kilometre size bodies began to grow in the nebula. As the Sun grew to about 30% of its present mass, pressures and temperatures in the solar interior ignited the nuclear furnace and the conversion of hydrogen to helium began. Observations on young stars suggest that the Sun underwent violent T Tauri and FU Orionis outbursts as it proceeded on its evolutionary path toward the main sequence.

Strong stellar winds began to disperse the nebula, thus limiting the ultimate size of the Sun (Shu et al., 1987).

Astrophysical evidence suggests lifetimes of a few million years before the nebula is dispersed. Thus infra-red observations which imply the presence of dusty disks around pre-main sequence stars indicate that such disks are dispersed on timescales of about three million years (Strom et al. 1989). Although this observation refers to the dust components of the nebula, it seems reasonable that once the dust has dissipated, the gas has gone as well, either by collapse onto Jupiter-like bodies, or by being driven away by T Tauri-phase stellar winds, which operate on even shorter timescales.

Widespread loss of volatile elements such as Rb relative to refractory elements such as Sr and of volatile Pb relative to refractory U and Th occurred in the inner portions of the early nebula. Venus, Earth, Mars and some meteorites are depleted in volatile elements, as shown by their low K/U ratios, and by the U/Pb and Rb/Sr isotopic systematics in the case of the Earth. This depletion thus appears to be typical of the entire inner solar system out to perhaps 3 A. U. at which distance, more primitive asteroids begin to dominate the asteroid belt (Bell et al, 1989; Gaffey, 1990).

Possible models for losing volatile elements include heating in small planetesimals. Such scenarios are judged unlikely since even a thin surface skin on a molten body inhibits loss (e.g., Gibson and Hubbard, 1972). More definitive evidence has ruled out loss of volatile elements by evaporation. Humayun and Clayton (1995) have demonstrated that the potassium isotope ratios are uniform in all solar system materials. Loss of potassium, a volatile element would alter the ratios. The most plausible hypothesis is that early violent solar activity swept away not only the H, He and other gaseous elements from the inner solar nebula within a few million years, but also volatile elements not condensed or trapped in planetesimals large enough (metre-km size?) to survive the violent solar activity.

PLANETARY FORMATION

There are two ways to form planets. One calls for the formation of the planets by fragmentation and condensation of the primordial solar nebula. Jupiter should be the prime example of such a process. However, there are two principal objections. The first problem is that Jupiter does not possess the solar bulk composition that would be expected if Jupiter were derived from a fragment of the primordial nebula: this gas giant has a (rock+ice)/gas ratio about 10 times that of the Sun. Secondly, the moment of inertia data for Jupiter show that it possesses a central core of 15-20 earth masses. At the prevailing conditions in the centre of Jupiter (20,000K; 40 megabars) rock and ice will be miscible with the gaseous components (Stevenson, 1985). It will thus not be possible for a core to "rain-out" in the manner of the metallic core in the Earth. At the temperatures and pressures within the Earth, there are both significant density differences and metal-silicate immiscibility (Stevenson, 1985) that enable core separation, in contrast to the conditions inside a giant planet. Thus in the case of Jupiter, it is necessary to form a massive core first, which can then collect the gas by gravitational attraction.

Thus although stars form by gravitational collapse of gaseous nebulae, it seems that planets in contrast are built up "brick by brick" from smaller bodies, a concept consistent with the apparent lack of objects, such as "brown dwarfs" bridging the gap between the smallest observable stars and Jupiter-size planets.

It is worth noting that only three of the giant planets, Jupiter, Saturn, and Uranus possess substantial regular satellite systems, (the capture of Triton was probably responsible for the destruction of any primordial satellite system of Neptune). Although these miniature solar systems around Jupiter, Saturn, and Uranus might have been expected to be similar, they are all quite

distinct. There is apparently no simple formula to produce satellite systems within our own solar system. Since all the planets, as well as the 60-odd satellites are different, it appears that a large element of chance has entered in the evolution of our present solar system. This conclusion has lead to the realisation that it is difficult, if not impossible, to construct general theories for the origin of planetary systems.

THE FORMATION OF JUPITER

Early formation of Jupiter (318 x Earth-mass) appears to be required for several reasons. It has to form early enough to deplete the asteroid belt (which now contains only 5% of lunar mass) in material, and to be responsible for the small mass of Mars (0.11 Earth-mass). Jupiter must also have formed before the gaseous components of the nebula were dispersed: astrophysical evidence suggests nebular lifetimes of perhaps 3 m.y. (Strom et al. 1989). Thus it is first necessary to form a central core of 15-20 Earth masses, which can then collect the H and He envelope by gravitational attraction.

How did such a large nucleus form so rapidly and so early so far (5 A.U.) from the Sun? Since it seems less likely that there were primary density inhomogeneities or a "lumpy" nebula, secondary processes connected with early solar evolution seem to be responsible. A plausible scenario has been suggested by Lissauer (1987). Observations on stars at a similar evolutionary stage suggest that as the Sun settles toward the main sequence and nuclear reactions intensify, intense solar winds will begin to clear the inner nebula (see discussion in Taylor, 1992).

As early strong solar winds, associated with the T Tauri stage of stellar evolution, swept out the uncondensed components from the inner nebula, water ice condensed at about 5 A.U. at which location the nebular temperature fell below about 160K. This condensation caused a local increase in particle density of the nebula at such a "snow line", which also acted as a "cold trap" for other components. Rapid accretion of a large ice and rock core can thus occur at this unique location, and act as a nucleus to collect a hydrogen and helium envelope. Clearly the accretion of the jovian core was decoupled from the accretion of the gaseous envelope. The low gas/ice + rock ratio in Jupiter implies that by the time that the core of Jupiter had grown large enough to collect a gaseous envelope, the gaseous nebula was already being dispersed, and that Jupiter simply ran out of material. Once Jupiter formed, this massive planet dominated subsequent evolution of the solar system. Depletion of material in the asteroid belt occurred both from accretion of material to Jupiter, and subsequent pumping up of eccentricities and inclinations of the remaining asteroids , so that the survivors have been unable to collect themselves into a planet. Others asteroids were tossed out of the system entirely (Binzel et al., 1990).

ACCRETION OF THE TERRESTRIAL PLANETS IN A GAS-FREE ENVIRONMENT

In the region of the inner nebula now occupied by the Earth and the other terrestrial planets, the gas was mostly swept away. Only rocky bodies, large enough (metre to kilometre in size) to survive the early intense heating and intense solar wind episodes from the early Sun, were left. These bodies grew by collisions into planetesimals of varying dimensions, a few of which reached the size of Mars (about 10-15% earth mass), before finally falling into the Earth or Venus, a process taking perhaps 50-100 million years.

There is much observational evidence that the Earth and the inner planets were thus built up brick by brick from a hierarchical suite of planetesimals. This evidence includes the existence of heavily cratered ancient surfaces on the Moon, Mars and Mercury, indicating that the bombardment with a wide range of projectiles continued after the solidification of the lunar highland crust at 4440 ± 20 m.y. ago (Carlson and Lugmair, 1988). However, these late-falling objects rarely exceeded 50-100 km in diameter, and

many may be connected with a late spike or "cataclysm" about 3800-4000 m.y. ago (Ryder, 1990).

Other evidence for the former existence of much larger planetesimals during planetary accretion comes from the obliquities or tilts of the planets. Even the giant planets have been knocked about, the most dramatic example being Uranus, lying on its side with its pole pointing toward the Sun, but with its set of nine rings and 15 satellites more or less in the equatorial plane of the planet, only Miranda showing a relatively minor deviation from that arrangement. The high metal/silicate ratio of Mercury is best explained by stripping of much of the silicate mantle during a large collisional event; other hypotheses encountering many difficulties (Benz et al., 1988).

The Earth's rotation may also be a consequence of a giant impact. Venus, in contrast, has nearly zero obliquity, and is rotating slowly backwards. These properties may result from the accretion of Venus from many small bodies, and from the lack of a giant impact on that planet (Wood, 1986). Venus has also retained a massive atmosphere probably due to the lack of very large collisions with that planet. It is usually considered that the absence of a primitive terrestrial atmosphere on the Earth and the thin atmosphere on Mars are due to removal by early massive collisions (Melosh and Vickery, 1989).

Accretion of planetesimals into the four observed terrestrial planets in the low density environment of the inner nebula is estimated to take between 10 and 100 m.y. (Wetherill, 1989). Since the dispersal time for the gaseous portions of the nebula are in the range of 1 to 3 m.y., Mars and the other inner planets must thus have accreted in an essentially gas-free environment. This is consistent with the extreme depletion of the noble gases in the Earth.

Most of the material in the Earth and Venus must have been derived locally from the nebula. Since the Earth accreted subsequently to the depletion of the asteroids, the asteroid belt was not a very good "quarry" from which to obtain material for the inner planets. The accretion of Mars took place in a zone depleted in planetesimals from the same cause (early formation of Jupiter) and this impoverished region, at 1.5 A.U. again does not seem capable of supplying much material for Venus or the Earth.

What was the size of the bodies which finally accreted to form the planets? There is ample evidence from the battered surfaces of planets and satellites throughout the solar system that they were hit by many large (>100 km diameter) bodies. The large tilts (obliquities) of most planets relative to the plane of the ecliptic are consistent with collision of very large objects (>1000 km diameter). These and other observations all point to the growth of planets mostly from a series of massive objects rather than from infall of dust or small (<10 km diameter) bodies.

DIFFERENTIATED PLANETESIMALS

Although most chondritic meteorites come from undifferentiated parent bodies, there is considerable meteoritic evidence for the existence of differentiated planetesimals within a few m.y. of To. The evidence assembled by Gaffey (1990) is persuasive that such bodies were differentiated early in the inner nebula. Metal, sulfide and silicate phases were already present before the accretion of the planetesimals; simple heating would result in separation of these phases in bodies large enough (100 km diameter?) for gravitational settling to occur. Since igneous meteorites with very old ages are known, planetesimals of such sizes must have formed within a few (20?) million years of To (Tilton, 1988).

Internal cooling of such bodies to temperatures below 1000°C is expected to occur on timescales exceeding 10^8 yr. The accretion of such hot, perhaps molten planetesimals to the growing terrestrial planets will produce two results: planetary melting during accretion and effectively instant metallic core separation. Metal-silicate

equilibration is likely to have occurred at low pressures in the precursor planetesimals.

This is in contrast to models which accrete the Earth from small cold planetesimals. In such scenarios, a cold undifferentiated interior is overlain by a hot mantle. Eventually, this unstable situation results in overturning, with reduced melted metal sinking to the interior. Core formation thus occurs rather late, and under high pressures, in such an accretionary sequence (Stevenson, 1981: Ida et al., 1987).

THE ORIGIN OF THE MOON

Hypotheses for the origin of the Moon must explain the high value for the angular momentum of the Earth-Moon system, the strange lunar orbit inclined at 5.1° to the plane of the ecliptic, the high mass relative to that of its primary planet, and the low bulk density of the Moon (3.34 gm/cm^3), much less than that of the Earth (5.514 gm/cm^3) or of the other inner planets. The chemical composition revealed by the returned lunar samples (Taylor, 1982) added additional complexities to these classical problems, since the lunar composition is unusual by either cosmic or terrestrial standards. Several hypotheses have been advanced to account for lunar origin:-

(a) Capture of an already formed Moon from an independent orbit is highly unlikely on dynamic grounds. The hypothesis provides no explanation for the bone-dry refractory element-rich composition. If the Moon was a captured body, it could be expected to be an example of a common and primitive early solar system object, similar to the captured rock-ice satellites of the outer planets. It would be an extraordinary coincidence if the Earth had captured an object with a unique composition.

(b) If the Earth and the Moon formed as a double planet system, one immediately encounters the problems of their differing density and composition. Various attempts to overcome the density problem led to co-accretion scenarios in which disruption of incoming differentiated planetesimals formed a ring of low density silicate debris. Models involved the break-up of differentiated planetesimals as they come within the Roche Limit (about 3 Earth radii). The denser and tougher metallic cores of the planetesimals survived and accreted to the Earth while their rocky mantles formed a circum-terrestrial ring of broken-up silicate debris from which the Moon could accumulate. However the proposed breakup of planetesimals close to the Earth is unlikely to occur and it is difficult to achieve the required high value for the angular momentum of the Earth-Moon system in this model. Such a process might be expected to have been common during the formation of the terrestrial planets and so satellites formed in this way should be common, but the Moon is unique.

(c) George Darwin proposed in 1879 that the Moon was derived from the terrestrial mantle by rotational fission following core formation thus producing a low density metal-poor Moon. However, the angular momentum of the Earth-Moon system, although large, is insufficient by a factor of about four to allow for rotational fission. If the Earth had been spinning fast enough for fission to occur, there is no available mechanism for removing the excess angular momentum following lunar formation. The lunar sample-return provided an opportunity to test this hypothesis which predicts that the bulk composition of the Moon should provide some identifiable signature of the terrestrial mantle. However, there are significant chemical differences between the composition of the Moon and that of the terrestrial mantle. The Moon contains higher concentrations of refractory elements (e.g., Al, Ca, U) and lower amounts of volatile elements (e.g., Bi, Pb). The Moon and the Earth have distinctly different siderophile element patterns. These differences between the chemical composition of the Earth's mantle

and the Moon are fatal to theories which wish to derive the Moon from the Earth.

(d) One proposed modification of the fission hypothesis uses multiple small impacts on the Earth to place terrestrial mantle material into orbit. It is exceedingly difficult to obtain the required high angular momentum by such processes, while once again, the Moon should possess some unique terrestrial signature.

None of these theories accounted for the high angular momentum of the Earth-Moon system, a rock on which they all foundered. In these scenarios, moons should be general features of planetary and satellite formation and moon-like satellites should occur around the other terrestrial planets. The models fail to account for the unique nature of the Earth-Moon system, and the very peculiar bone-dry composition of the Moon, and do not account for the differences between the lunar composition and that of the terrestrial mantle (Newsom and Taylor, 1989).

THE SINGLE IMPACT HYPOTHESIS

This was developed by A. G. W. Cameron (Cameron and Benz, 1991) basically to solve the angular momentum problem but it has accounted for other parameters as well in the manner of successful hypotheses, and has become virtually a consensus. The theory proposes that during the final stages of accretion of the terrestrial planets, a body somewhat larger than Mars collided with the Earth, and spun out a disk of material from which the Moon formed. This giant impact theory resolves many of the problems associated with the origin of the Moon and its orbit. The following scenario is one of several possible, although restricted variations on the theme: In the closing stages of the accretion of the terrestrial planets, the Earth suffered a grazing impact with an object about 0.15 earth mass (over 30% larger than Mars). This body is assumed to have differentiated into a silicate mantle and a metallic core. It came from the same general region of the nebula as the Earth, since the oxygen and chromium isotopic signatures of Earth and Moon are identical.

The impactor is disrupted by the collision and mostly goes into orbit about the Earth. Following the impact, the mantle material is accelerated, but the core of the impactor remains as a coherent mass and accretes to the Earth within about 4 hours. A metal-poor mass of silicate remains in orbit (Cameron and Benz, 1991).

This highly energetic event accounts for the geochemical evidence which indicates that at least half the Moon was molten shortly after accretion. The giant impact event vaporized much of the material which subsequently was recondensed to make up the Moon. This effect thus explains such unique geochemical features as the extreme depletion of very volatile elements, the bone-dry nature of the Moon, and the enrichment of refractory elements in the Moon in addition to providing an initially molten Moon.

MARS

A crucial piece of evidence for solar system evolution is the small size of Mars. This planet is only 1.5 A.U. from the Sun. Jupiter is 5 A.U. distant from the Sun, but is 3000 times more massive than Mars. The very small size of Mars and the absence of H and He in that planet are consistent with the notion that the accretion of Mars took place in a gas-free nebula subsequent to that of Jupiter. The most reasonable scenario is that Mars formed from a very depleted population of planetesimals left over from the formation of Jupiter. By this time, the gaseous nebula had dispersed, leaving a surviving population of differentiated planetesimals in the inner nebula.

Although Mars is only about 11% of the mass of the Earth, its surface is dominated by basaltic rocks. This basaltic surface invites comparison with both the basalts of the ocean floors and with the flood basalts on the Earth, as well as with terrestrial shield volcanoes. The southern hemisphere of Mars is broadly composed of an

Ancient Cratered Terrain, that is older than about 4000 m.y. based on the analogy with the lunar cratering record. Its composition is unknown, but there are a number of convergent lines of evidence that indicate that it is unlikely to be acidic or very different in composition from that of the basaltic plains that dominate the northern hemisphere. In contrast, this consists of volcanic plains and large volcanoes, all most likely basaltic in composition. The Viking Landers at the two sites in the Northern hemisphere were 4000 km apart but their X-Ray Refraction major element data were both similar and basaltic in composition.

Material from the Ancient Cratered Terrain is probably present in the fine material analysed by the Viking Landers. Since the terrain is heavily cratered, it should possess a high proportion of dust and finely comminuted debris. This material is likely to be a significant component in the planetary-wide dust storms. Although both Landers were in the northern hemisphere, the fine material analysed by the Viking Landers represents a planetary-wide dust average (analogous to terrestrial loess) and provides some kind of average sample of the surface. Thus the Martian crust is dominated by rocks with low silica contents and so provides some analogy with the terrestrial oceanic crust.

The ages of the volcanic plains, based on crater counting and stratigraphic relationships, extend over much of geologic time and basaltic volcanic activity thus appears to have continued through most of Martian history. A feature of Martian volcanism is the growth of enormous central volcanoes. Olympus Mons, 26 km high and 600 km in diameter, is the most extreme example. The curious circumferential scarp, up to two km high, that surrounds the base of the mountain is probably a consequence of outward sliding of this great pile of material. The Tharsis plateau (10 km high and 8000 km across; large enough to affect the Martian obliquity) is also probably mostly formed by volcanic activity. This localisation of volcanic activity over stationary hot-spots, contrasts strongly with the surface expression of terrestrial hot-spots under mobile plates, of which the most familiar example is the Hawaiian volcanic and Emperor seamount chain in the central Pacific.

MARTIAN BULK COMPOSITION

The SNC (Shergotty, Nakhla, Chassigny) meteorites come from a geochemically evolved planet. The presence of a trapped atmospheric component, similar to the Martian atmospheric composition recorded by the Viking Landers, is decisive evidence for a Martian origin for these meteorites. Thus we can study Martian samples in terrestrial laboratories. The Rb-Sr systematics and K/U ratios of the SNC meteorites indicate that Mars has about twice the volatile element budget of the Earth. Thus K/U ratios are closer to 2 x 103 rather than about 103 for the Earth. Mars, although volatile-rich, has a low abundance of the noble gases, probably due to atmospheric removal by early collisions (Melosh and Vickery, 1989). Although Mars is volatile-rich compared to the Earth and Venus, it is still much depleted in comparison with the primordial solar nebula values. Its mantle is iron-rich, the basic cause of the iron-rich lavas and the ubiquitous presence of iron oxides at the surface that produce the red colour. The Martian core probably has a substantial component of FeS that could act as a sink for the chalcophile elements which are so highly depleted in the SNC meteorites.

A SCENARIO FOR THE EVOLUTION OF MARS

A possible scenario for the evolution of Mars begins with melting of the planet. This is an inevitable consequence of planetesimal accretion. Core formation occurred early and a transient magma ocean formed. During this period the mantle was depleted in chalcophile elements, presumably scavenged by FeS into the core. The north-south crustal dichotomy is probably due to an early global convective pattern, perhaps aided by massive impacts; the greater thickness of the

lunar crust on the farside of the moon is usually attributed to a similar cause.

Large volumes of basaltic crust formed by partial melting, due to the high heat flux following the solidification of the magma ocean. This thick early crust was subjected to heavy cratering and now forms the ancient cratered terrain. Recycling of the early basaltic crust was difficult since the eclogite stability field is not reached near the surface on account of the low pressures on Mars. No plate tectonics appears to have operated on Mars, so that it forms another example, like Venus and the Moon, of a one plate planet. The absence of subduction has also inhibited the development of more acidic rocks, and the view is taken here that granites and similar evolved rocks are mostly restricted to the Earth (see extended treatment in Kieffer, 1992)

VENUS

The Earth and Venus are often thought of as "twin" planets. What similarities and differences exist? Venus is 320 km smaller in radius than the Earth, and its density (5.24 gm/cm^3) is 5% less than the terrestrial value of 5.514 gm/cm^3. This density difference however is mostly due to the lower internal pressures. After correcting for the pressure differences, the uncompressed density of 3.95 gm/cm^3 is close to that of the Earth (4.03 gm/cm^3) perhaps with a slightly smaller core mass, but not requiring any real difference in bulk composition. Venus has no detectable magnetic field, its surface temperature is 470°C, and the only detectable water is the atmospheric content of about 50 ppm. Venus rotates very slowly backwards (243 days), it has no satellite, and possesses a thick atmosphere (95 bars, mostly CO_2), which contains about 80 times as much of the non-radiogenic argon isotopes (36Ar, 38Ar) as the Earth. Thus despite the similarity in size and density there are major differences between Venus and the Earth, probably the consequence of a differing collisional history from the Earth.

THE VENUSIAN CRUST

How does the crust of Venus compare with that of the Earth? The Magellan mission has revealed, in stunning clarity, that the Venusian crust is dominated by basaltic lavas and the presence of extensive areas of granite, analogous to the terrestrial continental crust, appears unlikely on Venus. The high standing regions of Aphrodite Terra and Ishtar Terra on Venus are apparently crumpled-up basaltic lavas. The conclusion that the surface is dominantly basaltic is confirmed by the presence on the volcanic plains of over 50,000 small shield volcanoes, typically 1-10 km in diameter with slopes of about 5°. They resemble terrestrial oceanic floor seamounts in density and size range but there are topographic distinctions from terrestrial examples.

Some domes, called "pancakes", about 20 km across, appear to be composed of more viscous lavas They may represent Venusian equivalents of rhyolites or other silica-rich rocks formed from the voluminous basaltic magmas by fractional crystallization in small magma chambers. These "pancakes" are isolated occurrences and are not similar to the voluminous terrestrial granitic continental shields.

In summary, the Venusian crust appears to be dominated by basaltic lavas and the presence of extensive areas of more fractionated rocks is minimal. There is no sign of the operation of plate tectonics and there appears to be no equivalent on Venus to the extensive terrestrial mid-ocean ridge system. Venus must be losing its heat by simple conduction, in contrast to the loss of heat by the Earth which occurs mostly at the mid-ocean ridges, since the present amount of lava being erupted on Venus is about equivalent to that of the Hawaiian volcano, Kilauea, a mere dribble on a planetary scale.

Nor is there any sign on Venus of the great trench systems and it seems unlikely that any recycling of the crust back into the mantle is occurring on Venus. The crust is apparently too

thin for basalt to be transformed into denser eclogite which could sink into the mantle and undergo melting to produce more siliceous rocks and perhaps granites. There are many examples of compressional tectonics, such as the banded terrain of Ishtar Terra, which contains the major mountain ranges, up to 11 km high (Maxwell Montes). Coronae are large (150-1000 km diameter) circular features formed of concentric rings of grooves and ridges. They may be the surface expression of hot spots and of mantle upwelling. Other unique features of the Venusian surface include the closely packed sets of grooves and ridges or tesserae which appear to result from compression. Most of the surface features can be explained as resulting from mantle plumes. The dominant horizontal movements of the terrestrial ocean floors appear to be mainly replaced on Venus by upwellings and downwellings associated with mantle plumes. The absence of abundant water is probably the crucial difference between the two planets and Venus and the Earth are similar only in a "Jekyll-Hyde" sense.

THE AGE OF THE VENUSIAN SURFACE

Most of the surface is about 300 million years old (Strom et al., 1994). These ages are based on crater counting. No ancient heavily cratered surfaces, that are common on Mars, Mercury or the Moon, have been discovered.

Most of the craters appear relatively pristine and there is a scarcity of partially degraded craters. It appears that there was a massive resurfacing event over the whole planet about 300-500 million years ago. There are no impact craters with diameters below 3 km and few with diameters less than 30 km. This is a consequence of the blanketing effect of the thick (95 bar) atmosphere. There are numerous dark smooth craterless patches or "splotches" of kilometre dimensions apparently caused by shock waves impinging the surface due to meteorites which were too small to penetrate and which broke up in the atmosphere. Most of the ejecta blankets have a missing sector. This seems to be due to atmospheric turbulence engendered by the incoming meteorite or asteroid. The missing sector of the ejecta blanket thus indicates the direction of the infall of the impacting body.

A total of 950 impact craters are present on a surface of Phanerozoic age. One large crater has formed every 0.5 million years. Four large multi-ring basins with diameters exceeding 144 km are observed. These impact rates must be comparable to those on the Earth similar in size to Venus. Due to erosion and the presence of the oceans, only about 150 impact structures, mostly very degraded, have been located on the Earth on terrains extending back over 2 billion years. Several large events must have occurred during the Phanerozoic on the Earth and it is of interest to consider the effects of the best documented case: the impact at the Cretaceous-Tertiary Boundary.

CRETACEOUS-TERTIARY EVENT

"No fact in the long history of the world is so startling as the wide and repeated extermination of its inhabitants." (Charles Darwin, in Ralling, 1978)

The most massive event was the extinction of 90% of species at the close of the Paleozoic Era (Stanley and Wang, 1994). This catastrophe came close to extinguishing life on this planet. The causes of such extinctions, of which there are many in the geological record, are widely debated. Another major disaster was the extinction of the land-dwelling dinosaurs and the marine plesiosaurs and ichthyosaurs at the end of the Cretaceous Period, 65 million years ago, that ended the "Age of Reptiles". It was the most spectacular episode of a widespread extinction that destroyed at least 70% of species living at that time, including all land animals heavier than about 20 kg, and most shallow-dwelling marine species. Over 74% of the total phytoplankton and 95% of the zooplankton, including 97% of the foraminifera, became extinct. Several major groups, such as the ammonites, died at this time. The removal of the giant reptiles

facilitated the evolution of the mammals during the subsequent Tertiary Era. Many explanations have been offered for this catastrophe ranging from a nearby supernova to a more gradual decline of the various species. The discovery of evidence for the impact of a 10 km diameter asteroid that formed a 200 km diameter crater at Chicxulub in the Yucatan Peninsula, Mexico, at the end of the Cretaceous has provided a new and widely accepted explanation for this major extinction. (See extended discussion in Sharpton and Ward, 1990). The energy release is estimated at 100 million megatons of TNT equivalent. Among the most spectacular evidence for the impact are the world-wide hundred-folds enrichments of iridium (a meteoritic signature), grains of quartz shocked to hundreds of kilobars by the impact, and a deposit of soot so extensive that most of the terrestrial biomass must have been burnt. The impact excavated evaporite beds, and an estimated 600 billion tons of SO_2 was lofted into the atmosphere. Acid rains were produced both from this and from nitric acid produced in the atmosphere by the explosion of the asteroid. The environmental stresses caused by the collision include the following: For some hours, winds up to 500 km/hour and tsunamis swept over the surface. These were followed by some months of darkness from dust and smoke and resultant low temperatures. Wildfires and an H_2O greenhouse persisted for months, while a CO_2 greenhouse with temperature rise and acid rains continued for years. These effects destroyed most land vegetation (ferns were the first to reappear in the fossil record (Nichols and Fleming, 1990)) while the oceanic food chain was destroyed either by darkness or acid rain or both. Such effects seem adequate to account for the suddenness of extinctions in the fossil record.

EPILOGUE

One may answer the question of Albertus Magnus with the following comments. Chance events have dominated the formation of the solar system and the course of life. Other planetary systems doubtless exist, but the chances of finding both a clone of the Earth and of an evolutionary sequence that has led to intelligent life and to something resembling Homo sapiens seem highly improbable. Too many chance events have intervened.

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FULL CIRCLE: THE RESURGENCE OF THE SOLAR ECONOMY

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ABSTRACT. Solar Energy is our most ancient fuel and remains by far the most important energy foundation for activity on this planet. The intelligent use of solar energy was well understood by many ancient civilisations, but commercial use has suffered numerous collapses throughout history. This is because the economic foundations upon which it was based failed to account fully for the environmental benefits offered by this remarkable fuel. However, a fuller cost/benefit accounting of solar energy is beginning to enter the marketplace at the same time as numerous solar technologies are dropping rapidly in cost due to technical improvement. The alliance of these two factors is powerful, and should allow us to return to a solar economy over the next few decades. The process has already begun.

INTRODUCTION

Solar Energy: the name evokes the aura of a new field, full of exciting but untested possibilities. In fact, solar energy development dates from ancient times and has a history far longer than any of our modern commercial energy technology.

Solar is not only our oldest fuel, but it became commercial before other fuels, in the trade of wood fuel and charcoal, and in the construction of buildings with specifically solar features. Solar becomes commercial when you must pay for a collection and wide distribution system for it. This is true for all fuels. The commercial value we put on coal or oil arises from the extraction and distribution system constructed to access the fuel, rather than any intrinsic economic value in it.

It would be no surprise to anyone that, throughout billions of years of evolution, the energy economy of plants and animals rested almost completely upon solar energy in the form of direct warming and photosynthesis. But we often forget that humankind remains in a similar position today. Our preoccupation with the costs and the problems of commercial fuels blinds us to the fact that the commercial fuel market is thousands of times smaller than the solar energy required to warm our planet, grow our crops, and maintain the biosphere. The debate about solar energy is a debate about diverting one ten thousandth of the solar energy used by this planet to replace fossil fuels for commercial purposes. Given this perspective, such a diversion seems sensible, given the big trouble we are having with chemical pollution associated with non-renewable fuels.

It is mostly the commercial and technical history of solar energy of which I will address in this lecture. But this subject involves more than dry technology. It is a history of great hopes, great disappointments, and great achievements. There have been many extended cycles of development, often with complete obliteration of the technology at the end. It is a realm where idealism and philosophy are important ingredients. The bold navigators of the past can help us to better chart the future if we let them speak.

Solar energy is a diverse field technically, and different techniques arose at different times. More than that, the same techniques often arose several times. A good example of that is in the field of Solar building design.

SOLAR HOMES

Solar Architecture depends upon usage of the seasonal changes in elevation of the sun to make a building more comfortable than it would otherwise be. It represents a fine-tuning response which takes

advantage of the sun's apparent seasonal motion to optimise comfort in the home. The most basic situation is described in the words of Socrates (as quoted by Xenophon):

"In houses that look toward the south, the sun penetrates the portico in winter, while in summer the path of the sun is right over our heads and above the roof, so that there is shade."

These days, we fancy ourselves more advanced than the Greeks, but most modern homes are very poorly designed, so that considerable additional fuel is required to make them comfortable. But in ancient days, there were times when wood fuel became scarce and considerable thought was put into solar building design. Many classical Greek homes (see drawings in Butti and Perlin) were built with living spaces facing toward the equator, and Olynthus was an entire Greek town planned with a street grid which allowed equal solar access to each building. Such a plan was viewed as politically correct as well, fitting in with the democratic ideals of the time. Olynthus also used adobe brick dried by the sun instead of burnt brick. This saved considerable wood fuel in what today we would call invested energy. The Greeks lacked glass windows for their homes, but the designs remained effective. When solar heat was unavailable, charcoal was used to warm the home.

Priene was another such town, and there were no doubt many others. In fact, Aeschylus, the Greek playwright, suggested that a south facing orientation was indicative of a civilised people. In a clear anticipation of our so-called modern society, he describes Barbarians as follows:

"Though they had eyes to see, they saw to no avail. They had ears, but understood not. But like shapes in dreams, ...they wrought all things in confusion. They lacked knowledge of houses.....turned to face the sun, dwelling beneath the ground like swarming ants in sunless caves.

The Romans adopted many Greek ideas and in the case of solar building design, improved upon the Greeks by the addition of the first glass and mica windows. A first century Roman architect (Vitruvius) advised as follows: "One type of house seems appropriate for Egypt, another for Spain... one still different for Rome, and so on with lands and countries of different characteristics. This is because one part of the earth is directly under the sun's course, another far away from it, while another lies midway between these two.... It is obvious that designs for homes ought to conform to diversities of climate."

In modern Australia, we resolutely build poorly insulated brick veneer homes from Cape York to Hobart, regardless of the climate.

Rome was less democratic than the Greek ideal, and places on sun-facing hillsides were populated by the rich, with the poor finding any space they could below. Many large public buildings such as Baths also used solar heat trapping principles.

Glass began to be used by the wealthy in the 1st century AD, and the Romans also invented Greenhouses to grow plants out of season for the wealthy. The Emperor Tiberius had a fondness for cucumbers. According to Pliny the Elder, "There was never a day in which he went without." The emperor's kitchen gardeners, under obvious pressure to innovate, had special cucumber beds mounted on wheels which faced the sun, and in winter they placed cold frames of glass over the plant beds to retain the solar heat.

A Roman satirist (Martial), had a friend who enclosed his vineyard in glass so that "the jealous winter may not sear the purple clusters nor chill frost consume the gifts of Bacchus."

The Romans and Greeks even used the concept of thermal mass in floors. Roman writers recommended that a shallow pit be dug under the floor and filled with rubble and broken earthenware. On top, a mixture of dark sand, ash and lime was spread to absorb the solar heat. The rubble retained the heat until late in the evening. A

Roman architect (Flaventius) who was famous for self sufficiency manuals on solar heating and waste heat recovery from hot baths, advised that the dark floor would stay warm until dinner time and that the floor "will please your servants, even those who go barefoot."

The Romans were the also first to introduce solar law in the form of sunlight rights. We have found this difficult to enact in Australia because the influential classes use fossil fuel prodigiously, but in Rome solar architecture was only used by the wealthy. The Heliocaminus, or solar furnace, was a special sunroom in many wealthy Roman homes, and it was ruled in the second century AD that a Heliocaminus' right to sunlight could not be violated. This was later incorporated into the Justinian code four centuries later, indicating that sunrooms remained in use at that time, and that the wealthy were still there.

Solar architecture and proper alignment of streets arose in China at about the same time. Fuel has always been in short supply in China, and traditional Chinese home design used a similar layout to the Greeks, with the useful addition of rice paper windows to improve heat balance. Farm houses in China use this layout to this day.

With the Dark Ages, the understanding of solar principles in Europe largely disappeared although the Chinese traditions continued. The New World was developing it own solar path as well. The ruins of Acoma show that the 11th century Pueblo Indians of the American South West were designed in a similar manner to the Greek solar towns, allowing each home maximum winter solar access. Greek knowledge of solar technology was not lost completely however, resting in the Arabs and Spanish and thence to the New World by Spanish colonists who replaced the Indians. The Adobe structures of the Spanish Colonies were often built to a solar plan with south windows able to be shuttered and large eaves to shield from summer sun In the South West of the United States, this sensible architecture mostly disappeared when the English speaking colonists drove them out, and the wooden houses which were then built were better suited to the New England climate than to California.

But in Europe, the first solar architecture cycle was over. The use of glazing all but disappeared during the Dark Ages and, according to legend (see Butti and Perlin, 1980, p.41) had a less than promising rebirth in the Twelfth century when a Dominican monk was burned at the stake by the Church for forcing fruits and flowers in a Greenhouse. His sin was demonic tampering with the divine plan, a charge not dissimilar in seriousness to the current charge of tampering with the free market.

Glazing slowly recovered in Europe as glass technology improved, getting a boost in the extensive use of Greenhouses during the Little Ice Age of 1550 to 1850 and culminating in the grand conservatories of the Victorian Age. Conservatories became hugely fashionable, and people began to forget that the direction in which they faced was important. Those that faced the wrong way became large energy users and required extensive heating. When fuel rationing came into force in World War I, the fashion disappeared.

In Europe after World War I, many architects became interested in housing schemes for the populace which would use solar energy. In Germany, such schemes started off somewhat unsuccessfully using narrow north-south row house construction which eliminated winter sun and maximised summer sun (Mumford, 1933), but efforts then turned to smaller single story solar row houses running east west in groups of six. These were more successful, and used extensive glass frontage like later American designs, but were considered to be communistic by the new Nazi government and the programme was stopped in 1934.

Solar developments also occurred Sweden, Switzerland, and the Netherlands. In Switzerland, a solar cooperative community was created at Neubühl, near Zürich (Roth, 1948). This bears a

strong resemblance to early Greek planned communities like Olynthus, and as in the Greek case, personal welfare was the primary motivation. After World War 2, however, the advent of cheap fossil fuels halted further development.

In the USA, there were some experiments with solar wall glazing about 1881 by Professor Edward Morse, but although architects embarked upon a number of theoretical studies in the early 1930's, the main impetus came from the practical efforts of George Keck, an architect from Chicago. He designed a house of tomorrow for the 1933 World's Fair which incorporated an extensive glass structure, but for looks rather than for energy efficiency. However, he soon discovered the workmen were working inside the home with their coats off during zero weather outside, and became intrigued with the possibilities of home heating using south facing glass walls. In 1940 Keck designed the first modern solar home for Howard Sloan of Glenview, Illinois. This home used double glazing and purpose-designed overhangs to reduce summer overheating. Sloan was a real estate developer who then proceeded to market solar housing developments during World War 2. These were subsequently tested by researchers who agreed that there were benefits to the designs.

After the war, a large number of solar homes were built including prefabricated types. An Arizona architect named Arthur Brown developed a heat storage system consisting of a black interior wall which ran the length of the building (Brown, 1950). The living areas were south of the wall, and the sleeping areas to the north. At night, winter heat collected by the wall would have travelled through the wall thickness, heating the occupants in the bedrooms at night. This was intentional use of what is now called thermal mass to dampen out diurnal variations in internal temperature.

There were notable research efforts at MIT and elsewhere to understand the behaviour of solar homes. The first MIT home was built in 1939, and led to test reports (Hottel and Woertz, 1943) which became key documents underlying the technical advancement of solar thermal systems. The reports were the basis for the later CSIRO technical work in Australia which ultimately spawned an industry in solar water heaters.

At the University of Colorado, George Löf, developed a rooftop array heating air collector with a rock bed storage unit (Löf, 1944). This was integrated with a Gas fired heating system, and functioned as a fuel saver. The system saved about a third of winter heating fuel.

After the war the MIT programme continued until 1958, but such heating systems were too expensive in the period of cheap oil, and the programme was shut down.

BURNING MIRRORS

Many of the ancients seemed to be preoccupied in large part by building houses of their own and destroying those of their enemies. Regarding the latter activity, there was quite a long attempt at constructing a solar Doomsday Weapon. Solar isn't really very suitable for this sort of thing because the enemy can choose to fight on a cloudy day, but the effort persisted for a long time. Early burning mirrors used spherical geometry, but the Greek mathematician Dositheius invented the first paraboloidal mirror (Heath, 1921) in the third century BC and in a scientific paper a century later called "On the Burning Mirror" Diocles gave the first formal proof of the optical properties of parabolic and spherical mirrors (Diocles, 1976).

The references I have seen seem to agree that the reported use by Archimedes of burning mirrors to ignite the Roman fleet at Syracuse is a myth, as it is not mentioned by other historians of the period. While not taken up for war, burning mirrors were used to ignite sacred fires in Greece and in China. In Delphi, the sacred flame had to be relit with "pure and unpolluted flame from the sun.", and the Olympic flame is to this day. The Chou Li book of ceremonies, written in 20 AD, describes what were ancient rituals then: "The Directors of Sun Fire have the duty of receiving,

with the concave mirror, brilliant fire from the sun in order to prepare brilliant torches for sacrifice." (Needham, 1954).

During the Dark Ages the Arabs improved the understanding of the geometry of parabolic mirrors and by the Thirteenth century, Roger Bacon became convinced that the Arabs were working on the ultimate weapon. He advised Pope Clement IV that "The mirror would burn fiercely everything on which it could be focussed. We are to believe that the Anti-Christ will use these mirrors to burn up cities, camps and weapons." (Bacon, 1928). Bacon advocated building and testing the new technology to save Christendom and serve the aristocracy. But when the Pope died, the conservatives were successful in the next Papal election and decided that this new empirical view threatened the tradition of devine revelation. Bacon was cast into the dungeon.

The next major proponent of a Big Dish was Leonardo da Vinci, although his aim was peaceful. He planned a mirror four miles across that could supply heat for any boiler in a dyeing factory, and with this a pool can be warmed up because there will always be boiling water. This was the first dream of industrial solar power. As might be expected, the mirror was not completed. Unfortunately, he wrote in code so that his writings could not be deciphered after his death.

Throughout the sixteenth and seventeenth century, burning mirrors became larger and more sophisticated. While the main aim still seemed to be one of destruction there was an increasing trend to looking at the results experimentally. An eighteenth century research worker using a five foot diameter reflector made by Peter Hoesen in Dresden found that copper ore melted in one second, lead melted in the blink of an eye, asbestos changed to a yellowish-green glass after only three seconds, and slate became a black glassy material in 12 seconds.

Finally, the advent of gunpowder made the burning mirror obsolete as gunpowder was much more destructive and convenient. Nevertheless, the burning mirror effort sowed the technical seeds for the later development of solar thermal power.

SOLAR WATER HEATING

In Australia, while it was always possible to warm a container of water by placing it in the sun, the use of water heating technology is relatively recent. The origins of this technology lead back to eighteenth century France, where Horace de Saussure, a French naturalist, built a small 'Russian Dolls' hot box in 1767 using five square boxes of glass, one inside the other. The temperature achieved inside, 189.5°F, encouraged de Saussure to build a triple glazed wooden hot box which reached 228°F, above the boiling point of water, later achieving 240°F by using bottom insulation. By taking the box to the tops of mountains, he showed that the temperature achieved was similar in all locations, indicating that the sun shone equally well at all altitudes. This showed that the difference between air temperatures at different altitudes was due to differences in the retention of heat by the atmosphere rather than initial transmission. This was an early demonstration of the Greenhouse effect, caused mainly by water vapour in the lower atmosphere. De Saussure (1784) suggested that "Someday some usefulness might be drawn from this device, for it is actually quite small, inexpensive and easy to make."

Sir John Herschel, the well known astronomer, made a solar cooker from a similar hot box on a trip to South Africa in the 1830's, and Samuel Langley, the American Astrophysicist tested a hot box in 1881. Such devices showed that it was possible to heat water to useful temperatures with simple equipment. They were the ancestors of the solar hot water systems we use today.

During the late 1800s in the United states, people used water heating tanks attached to cooking stoves and operating using the thermosyphon principle. Some nameless early pioneers soon found that they could place such

tanks on the roof and produce hot water by direct heating of the sun. But the tanks lost heat rapidly in the evening because they were uninsulated.

The first true production solar water heating systems were invented by Clarence Kemp of Baltimore in the United States. In 1891 he patented the Climax Solar Water Heater in which the black tanks were placed inside a hot box which aided both collection during the day and retention of heat overnight. These became popular on the market about the turn of the century, and 1600 were sold in California by the year 1900. The payback time in coal saved was 4 years, and those who used wood appreciated the saving in labour.

The next major improvement was put on the market by Frank Walker, in which the box was integrated with the existing conventional water heating system so that hot water was available the year round. The tank was then made rectangular to fit the box envelope and insulation was improved. However, the system could not hold heat until the morning.

In 1909, probably the definitive step was achieved in system design. William J. Bailey of Los Angeles began selling a new system which used a coil of pipes in a hot box, mounted below a storage tank which was insulated. Water circulated by natural thermosyphon from the hot box - these days called a solar panel - to the elevated tank, and that hot water would stay hot all night because the tank could now be insulated. At night, the solar panel would cool down and the thermosyphon would stop. Backup electricity or gas was used with the tank for poor weather. This design is essentially the basic design used to this day, and systems using a design very similar to Bailey's are on sale around the world.

The new system was called the Day and Night Solar Heater and the panel design was soon improved by using a 'flat plate' collector attached to a zig-zag of water tubes, almost identical to current systems. It was more expensive than the Climax system but the increased convenience of the Day and Night system led to its eventual market dominance.

In 1920 more than 1000 systems were sold but the sudden discovery of large quantities of natural gas in the Los Angeles basin changed that. Gas companies offered monthly financing for customers with free gas for a year or two, and solar companies could not match this. As a company, Day and Night Solar heaters survived the onslaught by manufacturing an excellent gas heater using much of the automatic technology developed for the solar heaters. In 1927 only 40 solar heaters were sold and production ceased in 1941 as the war began.

In Florida, natural gas was not available, and a flourishing solar water heating industry was set up by H.M. Carruthers, who bought rights to the Day and Night system for the price of $8000 and his Oldsmobile car. This industry began just as the Californian solar industry was dying out. The Federal Housing Administration allowed financing of solar heaters at 4% interest and no down payment. As a result, more than half the population of Miami used solar water heating by 1941, with solar outselling conventional fuelled heaters by two to one (Scott, 1975). However, the war halted solar heater production by freezing supplies of copper. After the war gradually declining electricity costs and increasing copper costs led to a gradual decline in business, with the industry ceasing in the late 1950's as the USA entered a 15 year period of very cheap fossil fuelled electricity.

A sizable Japanese water heating industry arose after the second world war, catering to the traditional evening hot steaming bath popular with Japanese families. This used very inexpensive wooden or vinyl containers and the industry expanded to 250,000 per year by 1966, but the industry collapsed soon after under competition from cheap imported oil and cheap off peak electricity.

The focus then shifted to Australia, which had not participated in the earlier solar industry expansion. However, in the 1950s Roger Morse and Wal Read of the CSIRO assisted industry to develop solar water heating technology and the federal government encouraged installation on government buildings in tropical areas.

Solahart, a firm which developed from a machine tool company S.W. Hart, then developed the close coupled design now used by all Australian manufacturers. In this design, the tank ran horizontally along the top edge of the collectors, eliminating the need for in-roof tank installation. This is essentially the design used today. 40,000 collectors were sold between 1958 and 1973, but after the 1973 Oil shock and the Darwin cyclone, production increased greatly and Australian water heaters are now marketed around the world, with Solahart being the world's largest exporter of Solar Water Heating technology.

Currently Prof. Graham Morrison and the author are assisting Solahart to incorporate improvements into the design of their products which will allow much improved winter performance in mid-latitude regions such as Sydney and Melbourne. We now expect that systems in the near future will deliver between 80% and 90% of the hot water heating load in Sydney, compared with the present 63-70%. This should represent a substantial drop in pollution and energy cost in the near future.

SOLAR POWER

In 1860, Augustine Mouchot, a mathematician and possibly the greatest solar pioneer, wrote that "One must not believe, despite the silence of modern writings, that the idea of using solar heat for mechanical operations is recent. On the contrary, one must recognise that this idea is very ancient and in its slow development over the centuries it has given birth to various curious devices" (Mouchot, 1879).

The famous solar syphon built by Hero of Alexandria is the first known of such devices, and used solar heated air in a globe which forced water out through a tube. In 1659, Isaac de Caus built a variant of this device called a solar whistle. The expelled water from the solar syphon entered a partially water filled box and expelled air from the box left through two organ pipes mounted on the top of the box. This was inspired by the legendary 'voice of Memnon', a sound which is said by the historian Tacitus to have emanated from a Theban statue of the Ethiopian king Memnon when the statue was struck by the morning sun.

Mouchot was much more focussed on useful work. He tried to adapt the hot box of de Saussure to the production of steam, but the efficiency was much too low at such temperatures. He then created a heat trap from concentric bell jars, but this would still have been too large to be practical. He persisted, and decided that using reflector technology developed for burning mirrors with the heat trap could be the answer, mounting a solar reflector next to the trap. This worked well.

Mouchot created several key solar inventions in the process. He used the device as the first solar cooker, making what he called 'a fine pot roast in the sun'. He then used the device as the first solar still to purify wine into brandy, which he said had a "most agreeable flavour", and constructed a solar pump similar to the Hero design but capable of producing a spray of water ten feet long for half an hour.

After patenting the device in 1861, Mouchot then invented the first parabolic trough solar collector, using a copper collector tube, which powered the first solar steam engine in 1866. This engine was presented to Napoleon III. He then built a seven foot long version using a glassed-in double cylindrical boiler, complete with a tracking parabolic trough mirror running from a clockwork mechanism. However, he recognised that the sun only struck half of this absorber, so he moved to a new design in which the reflector was a truncated cone illuminating the absorber on all sides. This

was a great success and was able to drive a 1/2 horsepower motor at 80 cycles per minute.

In 1878, Mouchot and his assistant Abel Pifre built a larger unit for the Paris Universal Exposition . It was capable of pumping 500 gallons of water per hour, and he also demonstrated solar cooking, distilling, and the machine was even harnessed to produce ice.

Unfortunately, the cost of the silver plated mirrors used was prohibitive, and the new electrical technologies run by fossil fuel proved to be much cheaper. Mouchot returned to his mathematical studies in 1880, but his ovens and stills were used for a time in Algeria by the French Foreign Legion and the local people (Mouchot, p.263). Pifre continued the work and produced the first paraboloidal dish in 1880, which he used to run a printing press at a demonstration in Paris (Pifre, 1882). These gentlemen laid the foundation for several important technologies with their work. It was work inspired by the long term view, for Mouchot was very concerned about future energy supplies for Europe.

The initiative then passed to the United States. John Ericsson also contended that solar power was the answer to the rapid consumption of coal (Church, 1890). He had invented the first screw propeller for steamboats, and had built the successful Monitor ironclad steamboat which defeated the Confederate Merrimac in the American Civil War. Ericsson completed his first solar motor in 1870, claiming it as the world's first in spite of Mouchot's work. He used a parabolic trough reflector and bare metal absorber tubes without glass covers, and steam from this ran a small engine. Details of this motor were never released because of Ericsson's secrecy about details.

He then moved to a hot air engine in 1872, using a parabolic dish, but the cost of silvered reflector was prohibitive, as it had been with Mouchot's work. Ericsson then made a major innovation in the first use of silvered window glass, which did not tarnish and was much cheaper than silvered metal. In 1884 (Ericsson, 1884 and 1888) he revealed his new parabolic trough reflector design but before production plans were finalised he died in 1889, at the age of 86. Details of his last designs were never found.

In his obituary (Nature, 1889) it is said that "He continued to labour at his sun motors until within two weeks of his death. As he saw his end approaching, he expressed regret only because he could not live to give the invention to the world in completed form. It occupied his thoughts to the last hour."

In 1898, Aubrey Eneas built a prototype of a parabolic trough collector which was almost identical to Ericsson's design, but this did not achieve sufficient performance to run steam engines of the time. He then moved to a conical reflector like Mouchot's, except that the reflector at the bottom was moved out to allow more collection at the bottom of the absorber. Eneas designed a novel tracking structure to track the seasonal movements of the sun, and displayed the first prototype at an Ostrich farm in California, where it proved capable of irrigating 300 acres of citrus plantation, drawing 1400 gallons of water per minute from a 16 foot deep reservoir. The boiler was pressure self regulated, and the motor oiled itself. According to a reporter who covered the story, the operator had time off "to hoe his garden, or read his novel, or eat oranges, or go to sleep" (Butti and Perlin, p. 85).

Eneas sold one to a rancher, Dr. A.J. Chandler, in Arizona in 1903, but this suffered severe damage in a storm. Another, sold to John May near Wilcox Arizona worked well until hit by a hailstorm in 1904. These problems, plus a cost which was two to five times the capital cost of conventional steam plant, caused Eneas to abandon the effort.

Another approach was made by a refrigeration engineer Charles Tellier of France in the early 1880's. This used a solar pump based upon heating ammonia instead of water. Vapourisation of

ammonia requires only low temperature collectors, and Tellier used a device built on his shop in Paris to pump water via an expanding and contracting diaphragm (Tellier, 1885). Tellier never wrote up the results of his experiments, and mysteriously returned to work on refrigeration. But between 1892 and 1909, two American engineers, H.E. Willsie and John Boyle, built similar collectors which used warmed water to vapourise sulphur dioxide in a manner to the ammonia cycle of Tellier. A plant was built at Needles, California in 1909. It incorporated storage for the first time, in the form of hot water. However, although the plant worked very well, the technology was not commercialised by the inventors for reasons which are unknown.

In 1906, an inventor and solar visionary, Frank Shuman, who had studied the problems of high temperature systems produced by Mouchot, Ericsson and Eneas, also decided that the low temperature approach was the way to go. He produced working prototypes of systems similar to the Needles plant of Willsie and Boyle in Philadelphia. However, Shuman, unlike his predecessors, was an excellent salesman, and persuaded investors who had made money on his previous inventions to back development of a large scale solar power plant. When further funding was required, he formed the Sun Power Company in 1910 and built a trial plant of about 100 m^2 which used reflectors to augment the solar energy to the flat absorbers. Today, we call such a system a 'V-trough'. However, the economics of using low boiling point fluids were not encouraging, so Shuman designed a low pressure steam motor and converted the collector system to produce low pressure steam at slightly below atmospheric pressure in a sealed system. This was highly successful, delivering 3000 gallons of water per minute, with the collector achieving a heat collection efficiency of 30% and the engine a maximum of 32 horsepower.

However, the British investors called in a consultant, British Physicist C.V. Boys, and he suggested that a parabolic reflector concentrating on a two-sided fin boiler could do even better. This was something like Ericsson's design, but the low pressure steam system allowed good performance. The first system was installed in Egypt in 1913 and produced more than 41 kW, pumping 27 cubic meters of water per minute. It consisted of five north south axis sun tracking troughs approximately 62 metres long and 4 metres wide, for a total collection area of 1255 m^2. Technically, it was highly successful and reliable (Hally,1914).

Lord Kitchener, who attended its opening ceremony in Meadi, Egypt, offered a 30,000 acre cotton plantation in the Sudan on which to test solar irrigation, and the German government offered $200,000 in Deutschmarks for a sun plant in German South West Africa. Shuman spoke of building 20,250 square miles of reflectors in the Sahara, giving the world "in perpetuity the 270 million horsepower a year required to equal all the fuel mined in 1909" (Shuman, 1913).

This was the largest solar collector ever built up to that time, more than 15 times larger than Eneas' design, and would retain that crown for the next 65 years. Unlike present designs, it even included 24 hour operation through the use of a large hot water tank. It offered a payback time of only two years in coal-starved Egypt. The future seemed very bright, but soon after the outbreak of the Great War, the engineers running the plant were recalled to do war work and Shuman returned to the United States where he died before the war ended. In 1919 the great expansion in oil began with the formation of the Anglo-Persian oil company, and cheap oil soon became available in precisely the sunny desert regions which Shuman had targetted. Without Shuman, the project quickly died.

In the late 1880s another key development occurred on the road to solar power. Charles Fritts, an American inventor, invented the first photovoltaic cells (Fritts, 1885). These use the photoelectric effect discovered by Edmund Berquerel (1839).

Photovoltaic cells use the energy of photons of sunlight to promote electrons into the conduction band of semiconductors, where they can be accessed as direct electric current without the need for heat engines. The Fritts cells used selenium which had less than one per cent efficiency. Fritts' results were not believed by the classical physicists and engineers of the time (Siemens, W. 1885), but armed with the new quantum theory, they began to reproduce the designs of Fritts in the 1930s.

In 1954, a major step forward occurred when Gordon Pearson, Darryl Chapin and Calvin Fuller at Bell Labs in the United States produced the first silicon photovoltaic cell. By 1955 they had cells which were 6% efficient, and in 1956 they had produced the first PV panel .

Although early cells were extremely expensive and the age of cheap fossil fuel had arrived, for once solar technology was lucky, for the US Space program had begun in earnest and the new technology could provide the remote space power source required by artificial satellites, with cost as no object. The US government did not fund PV for terrestrial use at all, however. This had to wait until the mid 1970s.

Between the fifties and the seventies, the dream of nuclear power took solid hold, and solar energy was quietly forgotten. Only a few voices rose to question this course. In an article called "Nuclear Energy or Solar Energy?", George Russler (1959) wrote prophetically: "If one projects the problem into the future when all the world's conventional power plants, multiplied by a factor of 23 or more, are replaced by atomic plants, the enormity of the problem of waste disposal becomes apparent. Perhaps, on this scale, the problem may not be solvable."

And again: " Solar Energy is the one major source of energy which would not require several decades of development before large contributions could be obtained. Its use does not involve such serious problems as the control of a critical mass, or disposal of dangerous waste products, or operating health hazards. It does not require multi-billion dollar installations, nor huge concentrations of basic materials, nor elaborate controls. Sufficient engineering knowhow, a well as simple processes, are already available .... The only elements lacking are an appreciation of the urgency of the energy situation and a determination to get started."

Few people were listening, however. And decades were to be required for development, not because of technical difficulty, but because the determination to get started was not there.

NEW GENERATION

The current solar energy development cycle had to wait until the oil shock of the early 1970's. The oil shock was the result of an embargo by Arab nations against the United States as a result of the US assistance to Israel in the Yom Kippur war in 1973. It put and end to the era of cheap oil, and stimulated plans for new energy sources.

The United States concentrated on a plan based upon increased coal usage, shale oil and nuclear breeder reactors, but this fell into great difficulty. Solar funds were also increased around the world but at much lower levels than for research into fossil and nuclear fuels. The solar vs fossil fuel debate of the time was mainly centred around the possibility of dwindling supplies of fossil fuels, and around deteriorating local air pollution due to fossil fuel combustion in powerplants and vehicles.

Many of the current leaders in solar energy research began work at that time, and many new ideas were developed including new non-imaging optics, advanced selective surfaces, evacuated tube absorbers, advanced photovoltaics, and a host of minor advances. Australian researchers have played a strong role in all of these areas.

By the late seventies considerable progress was made in solar and wind technology, and for the

first time political measures began to be discussed in earnest. Soon after, U.S. Federal and State tax credits were enacted for renewable energy, and these were to have far reaching effects. In the decade from 1982, 15000 wind turbines were installed in California and 350 MW of solar thermal electricity. This development laid down the basis for both future industries.

However, by the mid-eighties we were in the 'greed is good' decade and the unconstrained market became king. Solar fell on hard times because the new economic religion had nothing in its scriptures about attaching value to the environment, so it was decided to forget about the problem.

In Australia, solar research centres were closed down under the guise of economic efficiency and research budgets were slashed while research budgets in other fuel areas remained high. Hagen and Kaneff (1991) claim that real Federal renewable energy expenditure dropped by an order of magnitude between 1978 and 1990.

It was even said in justification by some that nothing of note emerged from the research money expended in the late seventies and early eighties. Yet during the period in question, Australia actually reigned high in research and research papers, developed key technologies such as the cermet selective coatings, PV technology, non-imaging optics, solar parabolic dish technology, and did it on budgets which were minuscule compared to those overseas. Those of us in research at the mid to late eighties found it to be a very hard period, because of entrenched views in Government bureaucracies that solar was always going to be a niche player rather than a future dominant one.

This bias was not an Australian phenomenon but a global one. Conventional energy industry everywhere discovered solar and didn't like what it saw. In the UK, Department of Energy rankings which put renewables at the top of development priorities were reversed by a new committee. The conservative government would not reveal the composition of the committee for fear of exposing the members to public ire, but eventually the names came out, and it was composed of he executives of competing industries.

In the USA, research money suddenly evaporated, the solar energy research centre funding was slashed to a small amount and things were made difficult for many solar projects. The discrimination became petty; I recall driving to visit the impressive Solar One project near Barstow in the Californian desert and was having some trouble finding the site because there were no signs at all, because the Federal administration wouldn't allow them on Federal highway land. The plant was cancelled eight times by the Reagan administration and reinstated eight times by Congress, causing Martin Marietta, the plant contractor, considerable difficulty. The lesson to companies was clear - keep away from solar.

THE ENVIRONMENT TO THE RESCUE

Things were not looking good for solar energy development, but scientists had by now begun to warn of the possible impact of global warming. In 1986, the UN Bruntland Commission gave its findings in a report which was to have far reaching impact. It identified sustainable development as a necessity for our long term tenancy of the planet.

Sustainable comes from 'to sustain', with the definition given by the Shorter Oxford Dictionary being 'to keep in being; to cause to continue in a certain state; to keep or maintain at a certain level or standard; to preserve the status of." Clearly, the most infinitesimal net downgrading of the environment is not allowed, because eventually these changes will accumulate to destroy the system.

Sustainable development is a new approach which incorporates long term social improvement as a means of supporting environmental stability. I believe that this is in direct opposition to current

conventional economic theory. In the latter, the future is discounted to zero within a decade or two, so there is no long term accountability. The implications of your actions do not revert to you but to someone else. It as always been easier to make a profit if someone else will pay the bill for you later.

A UN process was set in train which resulted in the Rio Summit and Berlin Klimat 95 which have set an international direction toward limitation of emissions. This is being supported by findings of the Intergovernmental Panel on Climate Change (IPCC), which has this year (1996) demonstrated scientific evidence of human effects upon the climate. There is now fast rising international interest in clean energy technology as not only an environmental saviour, but a business opportunity.

ENERGY TECHNOLOGY FOR THE FUTURE

Renewable energy proponents have claimed for many years that stimulus of early production using marketplace measures would reduce costs substantially, allowing cost competition against fossil fuel and nuclear technology for he generation of electricity. This is now happening. I will describe only four important technologies, but there are many others in the renewable energy stable.

Wind Generation

The first significant cab off the rank is wind power. Because it uses no exotic principles, and has had a more continuous development experience behind it over the century in Denmark and elsewhere than other solar technologies, wind has been able to be quickly developed.

Wind is the kind of modular energy supply which can grow very quickly, and it provides a concrete example of the growth potential of renewable systems. The first wind generator was invented in Denmark in the 1890's, and the Danes and Americans slowly advanced the technology until the 1970's when wind energy received a boost from the oil shock. Installations were promoted by government incentives in California and Denmark in the 1980's and wind has now become a rapidly growing sector. Between 1982 and 1994, wind energy cost dropped by a factor of three, and 3000 MW of plant was installed starting with a base production of virtually zero. Danish subsidies of US$50 million ceased in 1989, but the Danes have been well rewarded by a new industry selling approximately 45% of world capacity.

Wind is not particularly limited by site availability. There is a very large wind resource in Canada and the United States which can be exploited relatively straightforwardly. Siting is very important because the energy extractable from the wind rises as the cube of the wind velocity. Wind sites are now divided up by class, and wind sites over class 5 (over 7.5 meters per second at 50 m high) are currently exploitable competitively. It is estimated by Grubb and Meyer (1993) that sites within the USA (in the mid-West) above this figure, with moderate land constraints, could supply 25% of total US electricity generation, and sites above class three (above 6.4 metres per second could supply 1.65 times current US generation under 'severe' site restriction criteria. In Canada, using severe site restriction criteria, the resource potential is 19 times current Canadian electricity usage, and nearly 3 times that of the USA and Canada combined. New Zealand is very well placed, having a large hydroelectric storage system for future wind systems, and a large wind potential.

Recent work (Grubb and Meyer) suggests that a wind fraction of 25 to 45% is feasible in a large national grid before fluctuation due to variability become unacceptable. Without storage systems, other renewable energy sources would be required in the mix. But this is still a very substantial contribution.

In Australia, total class 5+ wind resources exceed those of Europe by 20%. Previous estimates were low because wind speed

measurement poles were made too short. However, much wind is in low population density regions such as Tasmania or South-Western Australia.

Wind energy is currently selling electricity competitively in the USA at about five cents per kWh, and the Sacramento Municipal Utility District is building a 50 MW wind plant with projected energy costs of 4.3 cents per kWh(e). 2000 MW more is already contracted to be built in the USA before 2000. The newest advanced turbines being tested are aimed at class 4 operation below 4 cents per kWh(e). The ultimate wind electricity cost is estimated at US$0.03 per kWh (Flavin and Lensson, 1995; Cavallo et al, 1993), which would make wind the cheapest form of electricity of any kind.

The American Wind Energy Association's objectives for the year 2000 are:

- 10000 MW installed in the USA
- $4 billion industry per annum.
- costs below US 4 cents per kWh(e)

Globally, the second order generation potential, which includes many site restrictions, is estimated at 50000 TWh per year, compared to global electricity usage in 1988 of 10,600 TWh per year. Plants are being installed in India, China the UK, the former Soviet Union, and many others. There is even now expansive talk of global installations achieving 400,000 MW by 2020, about 10% of global electricity consumption.

Solar Thermal Electricity

This technology is about a decade behind wind, because it is more complex and had to start from a zero technical base in the late 1970's. However, solar thermal potential is very large, particularly if new designs are used which are not limited to desert regions.

The potential for solar thermal power is largest with low concentration technology, described in the following. The technology, mated with natural gas backup, could be used over about 2/3 of the United States and most of Australia with little variation in delivered electricity cost. Backup fuel use rises in poorer solar areas, but this variation is not more than a 0.5 cents per kWh(e). The compact design of technology such as the new Fresnel reflector plant described below would allow more than 10% conversion of total land area solar radiation to electrical power, accounting for spaces between the collector panels. Based on 6 kWh per day of solar, this is 0.6 kWh(e) per m^2 of land per day, or 219 kWh(e) per m^2 per year.

The 2020 target of 400,000 MW(e) suggested for wind generation is equivalent to 1000 TWh(e) or 10^{12} kWh per year, about 10% of global electricity consumption. For solar thermal electricity to do the same, the land area required would be 10^{12} kWh/219 kWh = 4.6×10^9 m^2, or 4600 km^2. This is a square 70 km on a side.

To provide the whole of global electricity consumption would require 214 km on a side. Available poor land is much larger than this. The area of Western Australia alone is 55 times the required size. 46000 km^2 is a large area in one block but a small one when distributed amongst the world's nations according to local requirements. For Australian requirements, primary energy use is approximately 1% of the global total, so the area for Australian requirements would be much smaller. However, it should be understood that we already use similar areas for conventional fuels (Worldwatch, 1990). The debate is not therefore one of resource availability. It is one of cost and practicality.

Solar thermal electricity has been successfully demonstrated on a large scale in California over the last 15 years, and newer technology is just breaking through at this time. But the technology in all cases has advanced far beyond what was achievable at the turn of the century. For example, the large parabolic trough Shuman plant of 1913 is similar in basic concept to the contemporary versions, but the efficiency of conversion in 1913

was about 3% at best. The last Luz plants built in California achieved a peak of 24%, an eight-fold improvement, and the next generation of solar thermal plants should achieve almost 30%. These days, high temperatures can be achieved without excessive losses, allowing big improvements in thermodynamic conversion efficiency because high pressure steam can be used.

Linear Tracking Systems

The majority of direct solar electricity world wide is generated not in photovoltaic arrays but in 8 large solar thermal plants in California built by an Israeli company, Luz. The plants have a capacity of 354 Megawatts. The research and development for the plants was privately backed, but the plants were built on market incentives offered by California and the Federal government.

The Luz technology descended from parabolic trough process steam technology which began to be developed in the USA in the late 1970's, and by Luz at about 1980. A 5576 m^2 process steam parabolic trough system installed (not by Luz) in Chandler Arizona in 1983 is still operating, and Luz installed two systems in Israel before moving to electricity plants.

The technology chosen by Luz used single-axis parabolic trough collectors that track the sun with a North-South axis of rotation (Fig. 1). The collectors are mounted parallel to the ground, which allows the use of big reflector units (because they are not elevated high into the air). The LS-3 collector has an aperture area of 545 square metres and uses 224 glass mirror segments (Jaffe et al, 1987). An 80 MW plant utilizes nearly 900 such collectors.

The Luz collector utilizes an evacuated-annulus receiver consisting of an inner stainless steel tube mounted in a concentric cylindrical glass envelope. The glass envelope is evacuated, which serves to minimize convective and conductive losses. To limit radiative losses, the outer surface of the inner (steel) tube is coated with a special wavelength-selective material—commonly known as a "selective surface"—that readily absorbs visible sunlight while emitting comparatively little in the infrared spectrum. Heat transfer oil is used. The operating temperature of current parabolic trough solar thermal electric plants exceeds 390°C.

The Luz plants are operated as contract electricity suppliers to Southern California Edison, and have so far proved to be more cost effective and efficient than US Government backed central receiver technology. The cost of solar electricity dropped from US$0.265 cents per kWh(e) in the first 1984 plant, SEGS 1, to US$0.086 in SEGS VIII (De Laquil et al, 1993). The average solar to electricity efficiency of the 1990 SEGS XIII plant is about 17%, about twice that of the Solar One central receiver of 1982 and about equal to proposed future central receivers of 200 MW size in the next century. Between 97% and 99% of all solar collectors have been available throughout operation.

Luz went bankrupt in 1991, when it could not fulfill its commitment to fund SEGS X. The Luz operations depended upon government tax breaks, and the government failed to meet its commitments to Luz (Lotker, 1991; Flavin and Lensson, 1995, p.146). The tax breaks required annual renewal, but the 1989 congress only passed 9 months instead of 12, forcing Lux to complete SEGS VIII 3 months early and raising costs. Then a faulty analysis by the Californian Finance Department caused a temporary revocation of the Luz property tax exemption, at which point Luz investors wound up the company. This has interrupted technical development for several years.

Luz is now renamed Solel and is attempting to restart the technology with plants in India and China. It is working on advanced versions of the technology which may reduce electricity cost to US$0.07 per kWh.

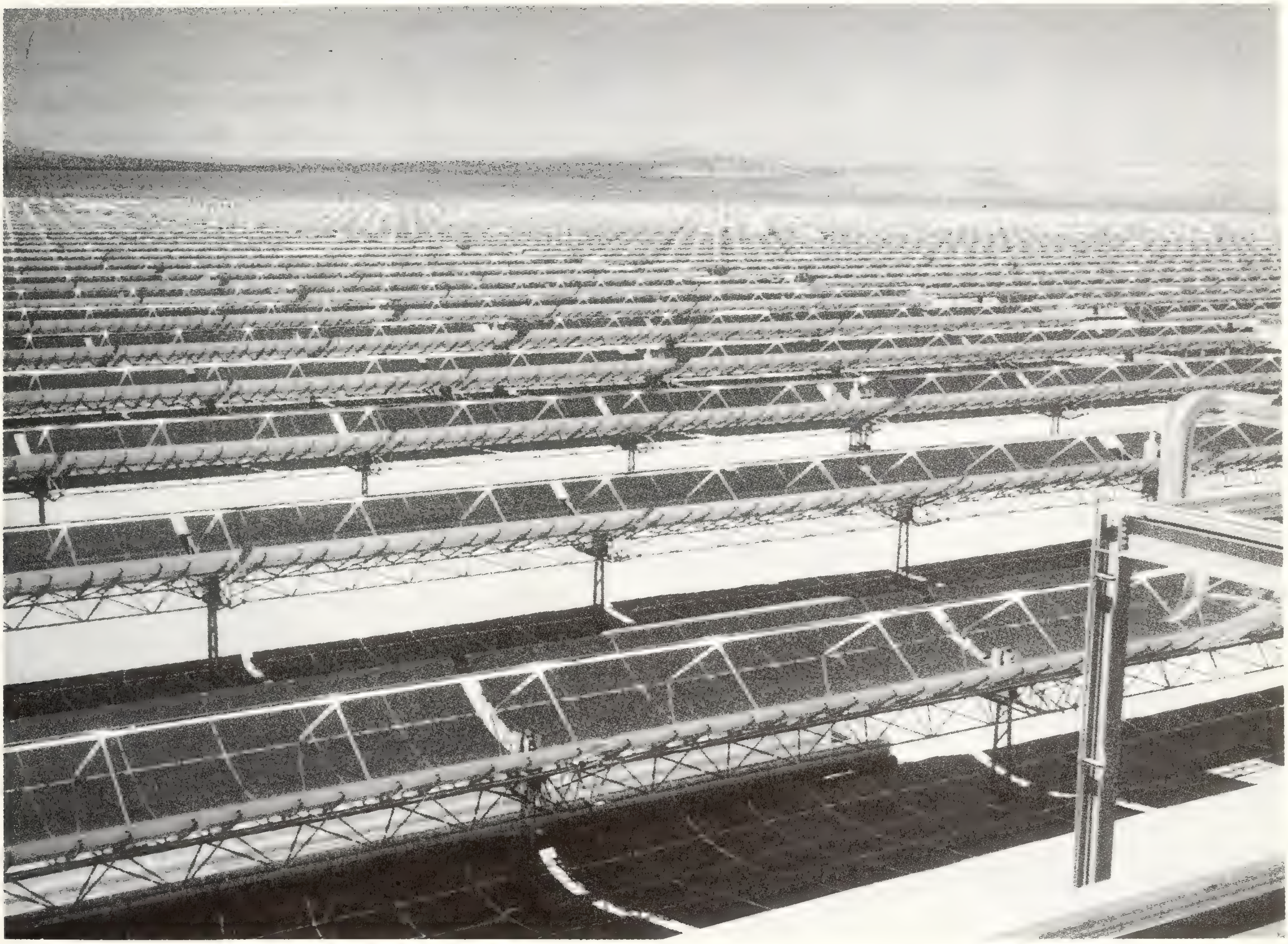

Fig. 1. Photo of Luz plant in California, taken by the author.

In 1991 our group at Sydney University developed new selective surfaces for solar evacuated tube absorbers (Mills, 1991; Zhang and Mills, 1992). These new surfaces have broken all world solar surface performance records, and they could reduce the future cost and complexity of solar thermal systems substantially below current levels. In Mills and Keepin (1993), Will Keepin and I showed that the use of such surfaces in new low concentration designs would dramatically drop the cost of systems, and allow increased performance. Such low concentration designs accept more circumsolar radiation, the light from the solar halo - allowing operation in non desert areas. Other issues canvassed in the paper were the benefits of hybrid solar/gas operation, with superheating being done by fossil fuel, the advantages of rock Bed thermal storage, which seems to offer the possibility of 24 operation without an increase in the cost per kWh. Biomass fuel could be substituted for natural gas later.

There are several low concentration designs which could use such evacuated tubes, but Sydney University is seeking patent protection on a particular design which uses linear Fresnel reflector construction (Fig. 2), with mirror strips and main receiver axis running East-West, but the axis of orientation could be North-South in some locations. The plant uses Dewar type all glass evacuated tubes as the receiver rather than the more traditional cavity receiver. The tubes can be arranged vertically in a linear elevated curtain-

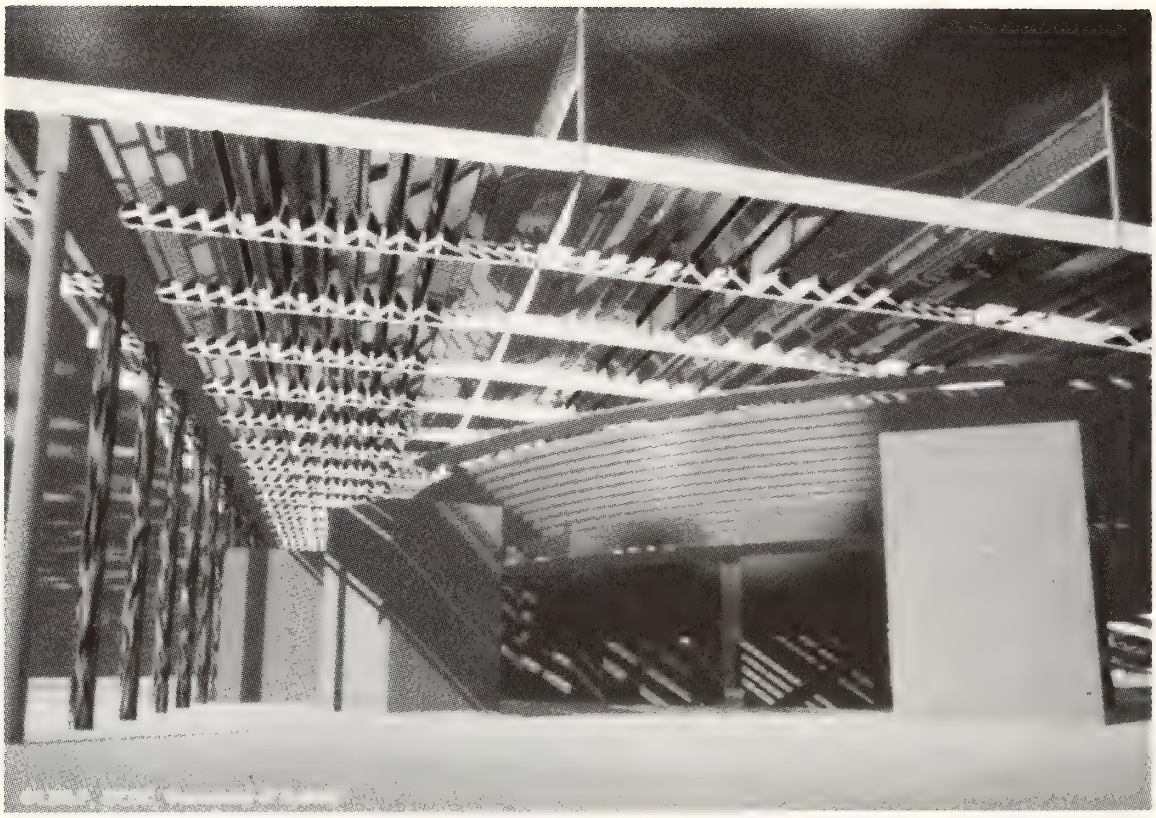

Fig. 2. Fresnel strip collector proposed by author visualised on a building at the 2000 Olympics. Visualisation courtesy of Lawrence Nield and Associates and the University of Sydney Department of Achitectural and Design Science.

like row to provide a favourably shaped optical target analogous to a 'double sided flat plate' receiver.

The design uses natural circulation of water/steam rather than incur pumping losses, which in the case of Luz are 13% of net output. It addresses many weaknesses in previous designs, and offers significant cost advantages over existing trough or dish plants, including low reflector cost (using flat or elastically curved reflectors), low structural cost, low receiver cost, high optical efficiency, low field losses, simple and low cost passive heat transfer, fully stationary receiver, high receiver thermal efficiency, and high ground use efficiency.

Generation costs of below A$0.07 per kWh ($US0.05) are feasible in good solar areas, and perhaps A$0.06 in the very best areas in the North and North West of Australia.

Central Receivers

Central receiver technology uses multiple mirror facets to concentrate solar energy on a receiver mounted on a tower. The idea dates from 1896, when C.G. Barr was allowed a patent for the concept of illuminating a solar engine on top of a tower, with the reflectors moving on railway cars surrounding the tower. In 1957, Russian engineers designed a 19000 m^2 plant of this type using 1293 railway flatcars grouped into 23 trains. A 1:50 model was built, so far as is known, the first such device.

The Power Tower concept using tracking heliostat reflectors was developed by Lorin Vant-Hull and Alvin Hildebrandt at the University of Houston in the early 1970's (Vant-Hull and Hildebrandt, 1976), and a number have been constructed around the world. The largest was the 10 MW Solar One plant commissioned in 1982. This ran successfully, although at poorer than expected efficiency, for several years. Recently it has been refurbished, provided with nitrate salt thermal storage, and renamed Solar Two, and it is hoped that this will lead to a 100 MW installation within a few years (Vant-Hull, 1991).

A European consortium is promoting a different design using a volumetric receiver which uses a forest of tiny black wires to absorb sunlight and air as the transfer fluid. A plan to build one in Jordan has been delayed for political reasons.

In a very interesting effort, the Wietzmann Institute in Israel is currently using small aeroderivative gas turbines as a possible alternative to conventional absorbers in their central receiver.

Paraboloidal Dishes

An Australian technologies under development the Big Dish (Kaneff, 1991) uses a somewhat traditional design of paraboloidal dish, but on a larger scale than any previously. The dishes are interconnected with steam lines to a central steam powerplant. It is hoped to cut costs to the point of achieving eventual competitiveness on grid, and a plan to put 28 such Dishes into a project at Tennant Creek in the Northern Territory is being evaluated. The Dish is also suitable for solar chemical fuels production and efforts are being made in that direct at ANU.

The other major Dish related activity uses efficient stirling engine generators mounted at the focus of a dish. Cummins, known for diesel engine technology, is actively developing this approach in the USA.

BIOMASS TECHNOLOGY

There are many thousands of Megawatts of biomass-fired steam turbine powerplants around the world using wood or agricultural residues like bagasse from sugar processing. About 9000 MW of this was installed in the USA as a result of Federal incentives introduced in 1978. These typically are small have low operation temperatures, leading to high cost of operation. As a result, most biomass systems rely on zero cost residues to allow viable operation.

A new trend is to use biomass in a gas turbine, which runs at higher temperatures and higher efficiencies than the small steam turbines. Of course, one cannot stuff trees into turbine inlets, so the biomass is modified into gaseous form, or gasified first.

Gasification is a two stage process, with biomass being partially combusted into charcoal and gas, with the charcoal then being used to convert the carbon dioxide and water into carbon monoxide and hydrogen. Closed versions of the technology were basically developed for use with coal, but have been recently adapted to use with biomass in plants such as the new 6 MW(e) Varnamo plant in Sweden (Williams and Larson, 1993), which uses gasified wood fuel run through a gas turbine, then pushing waste heat through a steam turbine to generate more electricity, and then low temperature waste heat from the steam turbine as district hot water.

To function as a large scale technology, the biomass must be grown sustainably, and this can raise costs compared to cuttings from old growth forests or agricultural residues. The cost and pollution associated with transporting biomass to a central plant can also be an important issue.

It was estimated that production of global residues in important industries were 56 exajoules in 1988. Using these residues in Varnamo type plants would provide as much electricity as was produced by all the world's fossil fuel powerplants in 1988. Of course, mobilising all such residues would be impossible, but it demonstrates that there is considerable potential in the area. Williams and Larson (p.778) suggests that 100,000 MW of advanced biomass fired capacity could be installed by 2020, about 7% of current world electricity consumption. Costs in the region of $US 0.04-0.05 are anticipated in large plants using agricultural residues.

Biomass may be an interesting partner with solar thermal power, since both can use the same heat engine and generator. Biomass is cleaner than coal because it contains no sulphur and the carbon is recycled, but there are some worries about nitrogen oxides being emitted.

PHOTOVOLTAIC TECHNOLOGY

In modern photovoltaics, impurities are added to the semiconductor material, which is usually silicon, to produce doped silicon. One thin top layer is doped with a material which has more electrons that the silicon atoms displaced; this is an 'n -type' material. An adjacent layer is doped with a material with an electron deficit; this is a 'p - type' material.

The junction between the two regions is called a 'p - n' junction and it creates an inherent electric field which separates the charges produced by the absorption of photons of solar energy near it. This tends to push the negative charges (electrons) to the back of the cell where a metallic contact removes the charges to the electrical load. Each cell produces a voltage of about 0.5 volts, and the cells may be added in series or parallel to produce any voltage and current combination. The circuit is made complete by a thin network of conductors on the top of the solar cell.

Photovoltaic systems comprise a module, a mounting structure which may be tracking or stationary, and a power conditioning system to present the power to the load in an acceptable state. PV power is DC, and must be converted to AC for grid use. Various losses occur from electrical connection and power conditioning, and costs are increased markedly if lead acid battery storage is employed.

Photovoltaic technology has established an early niche market in remote area power systems because of its simplicity and adaptability. It is very popular in developing countries, where more than 200,000 homes in Mexico, Indonesia, South Africa, Sri Lanka, and other countries use PV power supplies.

The ultimate position of photovoltaics in the electricity generation picture is unclear, but could be very important indeed. While the author believes that solar thermal electricity will be cheaper for grid connection over the next 10-15 years, after that time there is a clear possibility that PV will become cheaper as a supplier of 24 hour grid power, in possible combination with biomass fuelled combined cycle or advanced gas turbine plants. Most groups in the field believe that cost-competition against conventional fossil fuel prices will be achieved within 15 years, and that many major markets can be addressed before then.

There are several major avenues of photovoltaic development which are described in the following sections. All of them are attempting to eventually become cost-competitive against fossil fuel.

Single and Polycrystalline Technology

The evolution of silicon single crystal cells dates from Russel Ohl's early work at Bell Labs (Ohl, 1941). Since then, a wide variety of detailed improvements have taken place, including improved doping, diffused aluminium conductor backing, textured cell surfaces, and the more recent laser grooving technology (Chong et al., 1988) developed in Australia by Prof. Martin Green's group at the University of NSW.

Single crystal cells are the traditional method of manufacture, and these are produced by sawing slices of silicon, called wafers, from an ingot of crystalline silicon. This method is expensive and incurs waste from the sawing process. However, it has produced the highest efficiency cells to date, with some laboratory cells reaching 25%. Investment of energy in the process is very high however.

Nevertheless, progress is being made in reducing cell thickness, and the UNSW has pioneered a method whereby incoming photons can be scattered sideways in a thin film, increasing the chance that they will be absorbed. Recently, a thin film polycrystalline cell achieved 21% at the UNSW, a new record. In addition new cell multilayer construction has been proposed by that group in order to achieve high performance using cheaper low grade construction. Recently Pacific Power contributed $45 million to start up Pacific Solar, a company based around advanced thin film PV technology originated under Prof. Martin Green at the University of New South Wales.

New developments in thin film work being undertaken around the world and by three groups in Australia, and success in this area could see considerable expansion of the industry within 5 years. The technology continues to drop in cost, as

with the other renewables. Module supply contracts have fallen from A$28 per peak Watt (1993 Dollars) in 1980 to below $3 for a recent Malaysian contract. The Green group are proposing module costs below $1 per peak Watt.

PV Solar Concentrators

Another means of attacking the problem of high cost to minimise the area of PV cell used This is possible because PV cells can be designed to accept very high concentration of sunlight with high efficiency. The technology then is expressed as a solar concentrator, with sunlight being concentrated on cells areas tens or hundreds of times smaller than the collection aperture of the solar collector. Efficiencies can be quite high because more expensive multilayer or Gallium Arsenide cells can be used and a 20% efficient module using a Fresnel lens concentrator.

This approach sacrifices the simplicity of the simple PV panel, and it is not a likely candidate for usage in the domestic sector for his reason. However, for grid power generation the approach is simpler than using a heat engine with a solar thermal concentrator, and potentially very reliable. At this time, solar concentrators are still more expensive than their solar thermal counterparts because high solar cell costs still drive up system costs. However, projected costs for solar concentrating systems of the future are not dissimilar from those of advanced solar thermal, at between A$0.04 and A$0.10 cents per kWh for large plants of 100 MW(e) depending upon financial assumptions.

Amorphous Photovoltaics

These use a non-crystalline material as the solar absorber. There is a Photovoltaic effect in such materials which was first noted by R. Chittick and colleagues at the Standard Telecommunication Laboratories in 1969, and developed by Chris Wronski of RCA laboratories in 1974. These materials have a much higher absorption coefficient than polycrystalline silicon, and can be made much thinner. The potential for inexpensive cells made of such materials was soon realised, by the Japanese in particular, who developed a new industry based around such cells being used in consumer items such as wristwatches and other consumer items.

The efficiency of amorphous silicon has been historically much lower than for polycrystalline material, but has been rising steadily. However, amorphous cells were found to lose efficiency to about 6% after extended exposure to sunlight and this has compromised initial optimism. Nevertheless, the consumer market has made this type of cell very popular and it now comprises about 30% of the market. Amorphous silicon can be combined with other amorphous materials such as Cadmium Indium Diselenide (CIS) to produce cells with up to 15% efficiency, and it may ultimately be possible to produce stabilised efficiencies of 18% with such material. However, the recent 21% performance from thin film polycrystalline silicon cells will make life difficult because the cost of the basic material for both cell types is fairly low compared to other balance of system costs, and silicon is both common and non-toxic.

Predicted future module prices for Amorphous silicon are of the order of $A 1 per peak watt, and thus are about the same as for the other PV technologies. A Japanese company is rumoured to be close to the marketing of amorphous Si PV near this cost.

Photovoltaic power has established an early niche market in remote area power systems because of its simplicity and adaptability. It is very popular in developing countries, where more than 200,000 homes in Mexico, Indonesia, South Africa, Sri Lanka, and other countries use PV power supplies. New developments in thin film work being undertaken around the world and by three groups in Australia could see considerable expansion within 5 years.

The technology continues to drop in cost, as with the other renewables. Module supply

contracts have fallen from A$28 (1993 Dollars) in 1980 to below $3 for a recent Malaysian contract.

PV may have to face tough competition for other energy sources on grid. However, PV has some markets to itself, and my personal belief is that the greatest environmental value of PV may be in providing 'on roof' supplement power for future electric cars, even the majority of the power in some cases. This development would strongly drop net NO_x emissions as well as carbon emissions, and would at the same time extend the range of such vehicles. It is a suitable high cost energy market, because PV would compete with a taxed fuel burnt at poor efficiency.

TIME FOR THE USERS TO PAY

In Australia, the economy is heavily based upon coal and oil, and industrial giants often seem to have the final say on issues such as carbon taxes and forests.

But our society is more enmeshed in polluting behaviour than it first seems. George Wilkenfeld (1990) has shown that Australia's energy related emissions are dominated by 43% from electricity generation, and 26% for transport related emissions from fuel usage. However, a recent paper by Parikh and Watson (1995) at the University of Melbourne breaks down vehicle manufacturing emissions and shows that domestic vehicle emissions during construction are perhaps 90% of lifetime vehicle emissions. In other words, much of manufacturing emissions are a result of the motor car as well. All up, motor vehicle related emissions probably rival those of the power sector, although there would be some double counting of electricity used in manufacturing vehicles.

What this implies is that a very significant share of our total manufacturing activity is devoted to polluting technology like motor cars. This includes the aluminium industry for engine blocks, the steel industry, rubber, glass, electronics, and so on. Power generation is also a large industry. These industries employ many Australians. However, they also cost Australians a terrific amount in money and invested labour. We complain about two adults per family having to work full time to cover the house payments, but most families now have two cars. Compare the finance costs of purchasing and running several $25000 cars over 25 years against those associated with purchase of the family home!

The above shows we have to be very careful in how we shift to a clean economy so that the whole manufacturing ecology can be weaned from fossil fuel without social and industrial dislocation. But it can be done. We can still have a car industry if they are electric or alcohol powered. We can still have a power industry if solar power plants are used. However, to do this, we have to intervene in the economy to realise true market value of renewables.

Carbon emission regulations on powerplants and cars which include invested pollution could affect perhaps 80% of the energy emissions 'market'. Regulation can be targetted very narrowly and still have a massive and beneficial effect. However, a most damaging aspect of the current economic view is its de facto opposition to market intervention on behalf of the environment.

The last decade has clearly demonstrated that competition is often necessary for economic efficiency. To that extent the free marketeers are right. But the notion of an unconstrained market is preposterous; that is why we have laws. The 'real world' is not one of macho business takeovers and massive deficits, but of crashing fish stocks, disappearing soil futures, and air filled with things that shouldn't be there. We already regulate other activity which is dangerous to the community. Degradation of the environment also such an activity, possibly the most dangerous of all. However, competition and efficiency can be maintained within such a regulated market. Indeed, we are heading toward such a synthesis of market and environmental principles.

As an example, the NSW government has recently split up the electricity industry in NSW as an aid to competition and efficiency. However, the same government is introducing direct market intervention in the energy sector which is an expression of community value for the environment. The market may compete freely within these parameters. Redneck industry tends to view this as market bias. But, as the NSW Sustainable Energy Fund Working Party (SEF, 1995) states: ".....there are a number of barriers to the introduction of these technologies. The most notable include.. [several barriers].. environmental costs (externalities) not included in prices." The so-called 'free market' poorly accounts for true total societal costs. It must be restored to balance. This is 'user pays' in the strictest possible sense.

IN CONCLUSION

It is clear that solar technology is under highly active development, production is at the highest levels ever, and costs in all technologies are dropping very rapidly. However, the history of solar energy is one of a technology which is highly sensitive to initial cost price, and to the financing of that cost. If the cost and/or financing structure is right, the technology competes very well as did solar water heaters in Florida, and as do present solar systems in Darwin today.

The solar industry died in California in 1920 because of high cost, a cheap competitor the lack of financing and the fact that no appropriate value was put upon clean operation. Today we finance electricity and gas central facilities for the consumer but still do not provide the same service for a domestic solar collector.

The importance of the recent NSW government innovations and other similar measures emerging around the world is that for the first time in history, something closer to the real value of renewable energy to society is at last about to be entrenched in the economic system, and hidden subsidies historically propping up polluting fuels are gradually being removed. The valuation of renewable energy need not be perfect, and indeed the environment can never be fully valued in purely economic terms. But it is probably enough to supply a modest environmental rebate and long term financing of capital cost.

Most renewable systems are close enough to conventional cost that they would expand rapidly with such assistance. The is much evidence that this will allow sufficient production volume to achieve low cost. Once high volume production is achieved, even fully justified environmental subsidies may not be required.

In older times the advantage that a renewable technology might have could be quickly eclipsed by a new underpriced fuel or a war. Today a firmer foundation is emerging. This foundation is not based upon resource scarcity or a local pollution advantage, but upon a mix of economic and environmental criteria which reflect true social and environmental requirements required for our long term tenancy of our planet.

For early Humankind, there was no choice but to use solar energy. The necessities for individual survival which ruled us then are now being replaced by the necessities of global survival. But the choice remains the same. The circle is nearly complete.

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CONSCIOUSNESS AND QUANTUM MECHANICS.

Max.R. Bennett

with illustrations by Gillian Bennett

TWO GREAT MYSTERIES: CONSCIOUSNESS AND QUANTUM MECHANICS.

Quantum mechanics provides a theory for the behaviour of elementary particles and atoms. Even though it has been enormously successful in this task, the conceptual foundations of the theory are still a matter of hot debate. Mysterious dilemmas emerge as one probes deeper into the meaning of quantum mechanical ideas. Given that consciousness is itself such a mystery, some pundits have suggested that the spate of publications over the last decade on the possibility that quantum mechanical principles are needed to explain consciousness arise from the conviction that two such fundamental mysteries must be related! Perhaps the foremost exponent of the idea that quantum mechanical effects are involved in consciousness is the great mathematical physicist Roger Penrose. However Francis Crick, perhaps the greatest biologist of this century, dismisses the idea entirely. This article sets out the arguments so far developed for a role of quantum mechanical effects in consciousness. Suffice it to say that no quantum principles have yet been needed to explain any neuroscientific phenomenon observed in the laboratory, with the possible exception of the interaction of photons with the photoreceptors of the eye. But then, of course, is consciousness a laboratory phenomenon?

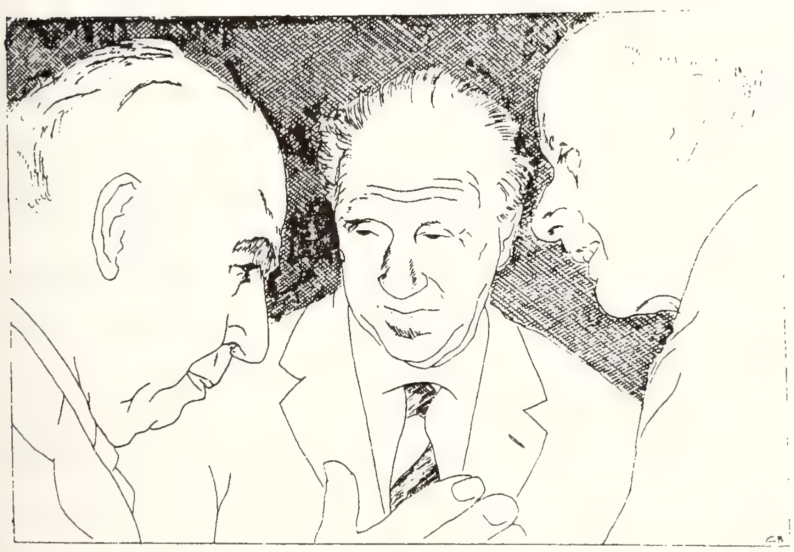

Figure 1. The founders of quantum mechanics in discussion together, 1962. Niels Bohr (left), Werner Heisenberg (middle) and Paul Dirac.

QUANTUM MECHANICS

The problem confronting the founding fathers of quantum mechanics (Figure 1), concerning the behaviour of subatomic particles, is best illustrated by means of the following experiment. Consider an apparatus consisting of an element (H) that gives rise to electrons and shoots them out through a very narrow hole A2, as shown in Figure 2A. The dots in this figure indicate the pattern of the positions of electron collisions built up on a scintillation screen when many pulses of the electron gun have been activated. Note that the extent of the scatter becomes greater as the hole A2 becomes smaller than a certain value. An additional hole A3 is now added to the apparatus, as shown in Figure 2B. In this case the expected pattern of electron collisions is simply the addition of two patterns like that in Figure 2A. However the actual observed pattern of collisions is quite different,consisting of regions of high density collisions alternating with regions in which there are no collisions at all.

This surprising result has an analogy with the propagation of waves through holes. Figure 2C(a) shows wave fronts (vertical lines) propagating through a hole which is much larger than their wavelength whereas (b) shows that the waves spread out when they propagate through a hole that is of similar or smaller wave length; this is analogous to the increased scattering of electron collisions as the hole becomes smaller in Fig 2A.

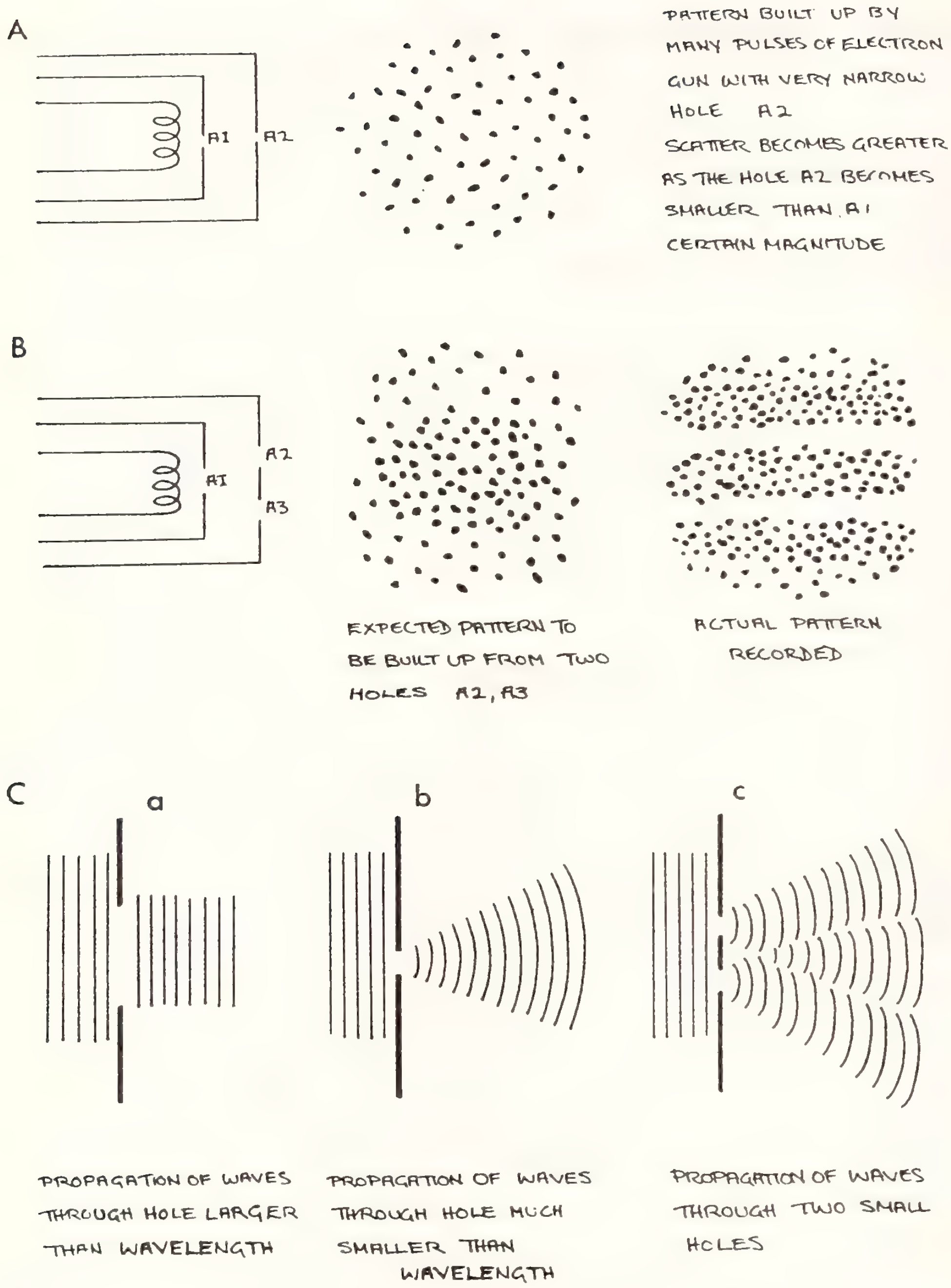

Figure 2. Experiments illustrating the quantum mechanical behaviour of subatomic particles.

In Figure 2C(c) the waves are made to propagate through two holes; in this case the waves through one hole interfere with the waves through the other, so that in some cases they reinforce each other and in other cases negate each other, The consequence, as shown, is that there are regions where the waves are strong and these alternate with regions where there are no waves. The situation is analogous to that of the pattern of electron collisions shown in Figure 2B.

BOHR'S INTERPRETATION OF SCHRODINGER'S WAVE EQUATION.

Schrodinger's wave equation provides a quantum mechanical description of this behaviour of electrons and is interpreted in the following way by the adherents of Niels Bohr of Denmark (Figure 3) and for this reason is called the Copenhagen interpretation. An electron is considered to be in a superposition of the different states of the observable which is to be measured, say its collision position on the scintillation screen in Figure 2B; that is to say the electron is considered to be at several different positions on the screen , as given by the solutions of Schrodinger's equation. The measuring apparatus (namely the scintillation screen) used to determine the position is also in a state of superposition with the different states of the observable, namely the collision positions. According to this interpretation, when an observer looks at the scintillation screen a superposition of observable states occurs involving the screen and the observer's brain. This piling on of states of superposition can only be terminated at the level of consciousness. All these correlated states can be ascertained by the deterministic Schrodinger wave equation. The question then arises as to where does the discontinuity occur which leads to the collapse of all the eigenstates except that one associated with a particular position on the scintillation screen, namely that observed? Schrodinger's wave equation for the electrons passing through the two holes of the partition in the experiment of Figure 2B therefore has solutions which give non-zero values for the position of electron collisions in those areas in which a position measurement might ultimately find that a collision has occurred. In the standard Copenhagen dogma the superposed

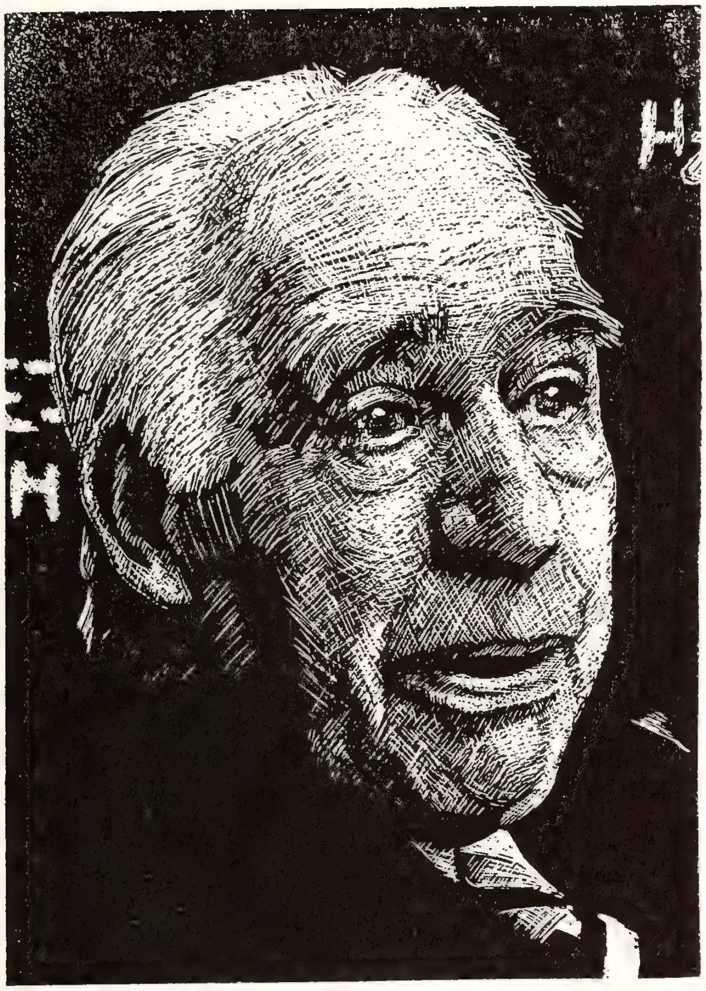

Figure 3. Niels Bohr (1885 - 1962).

positions of the electron collision all exist in reality up to the moment that a measuring device is used by an observer to determine the collision site; at this time the wave function collapses to zero at all sites except one.

The extraordinary implications of the Copenhagen interpretation of quantum mechanics is illustrated by means of the famous thought experiment named Schrodinger's cat, which is illustrated in Figure 4. Electrons are fired at a partition with two holes as in Figure 2B. If the electrons appear in the middle of the scintillation screen they trigger via a light sensing photoelectric tube, the release of a hammer which smashes a glass capsule of cyanide that kills a cat, resident in the same closed box as the apparatus. The position of the electron on the scintillation screen is a quantum mechanical problem, so the solution of Schrodinger's equation gives the superposition of states of the electron being at the different positions on the screen. The photoelectric tube and the hammer also have correlated states with the electron positions that are given by Schrodinger's equation; these involve (a) whether the tube is excited to give a current or not (for instance) and (b) the position of the hammer (for instance). Finally, the cat is part of this quantum system with states in which it is dead or alive. In this isolated quantum system then, the paradox arises that the cat is neither dead nor alive. The Copenhagen interpretation is that this chain, called the von Neumann -chain, is completed by an observer who looks into the isolated room. The conscious observer then becomes part of the quantum system. According to Eugene Wigner, this chain is broken but at the level of the mind , so that all the different states given by Schrodinger's equation collapse but one, and the cat is found either dead or alive. In practice the Copenhagen interpretation of quantum mechanics draws an arbitrary line of demarcation between the quantum world (of say atomic particles) and the classical world (of say measuring instruments and human brains), as illustrated by the cartoon of Figure 5. Application of Schrodinger's equation is then confined to the quantum world.

BOHM'S INTERPRETATION OF SCHRODINGER'S WAVE EQUATION.

David Bohm's interpretation of Schrodinger's equation escapes these dilemmas of the Copenhagen school. This is illustrated by the following thought experiment given in Figure 6. A laser sends a photon to a beam splitter at which the photon's wave function splits and passes along pathways A and B, whereas the photon continues along just path A; it is then reflected with its wave function into a switching box. If the switch is on then the part of the wave function which took the same route as the photon, together with the part which did not, meet at D, where they give the interference patterns shown on the screen. These patterns indicate the probability distribution of where the photons impact on the screen. If the switch is off then the part of the wave function that did not take the same route as the photon never meets the photon again; this is decisive information for the photon, which then acts as a

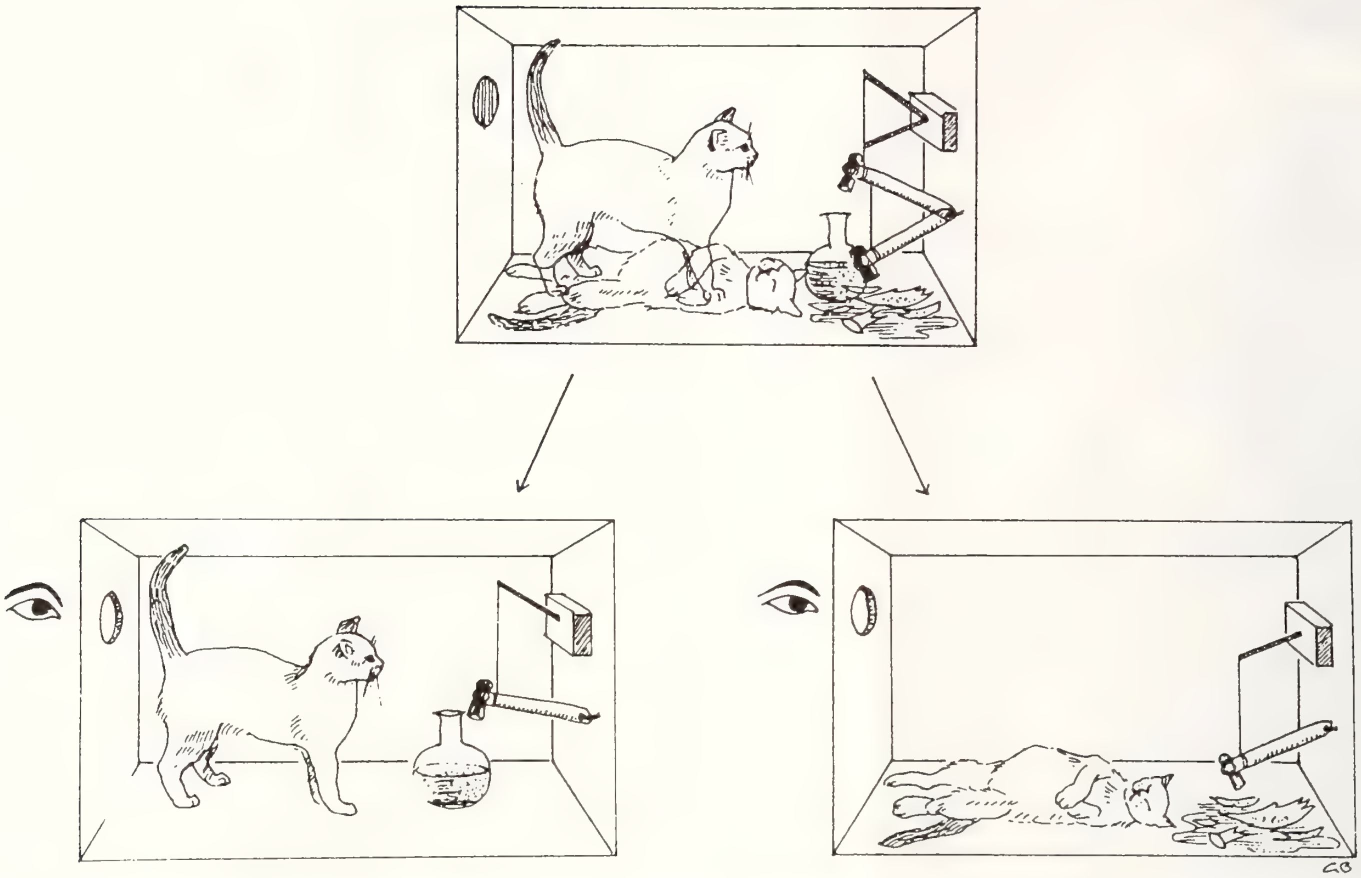

Figure 4. Schrodinger's cat highlights the dilemmas presented by the Copenhagen interpretation of quantum mechanics.

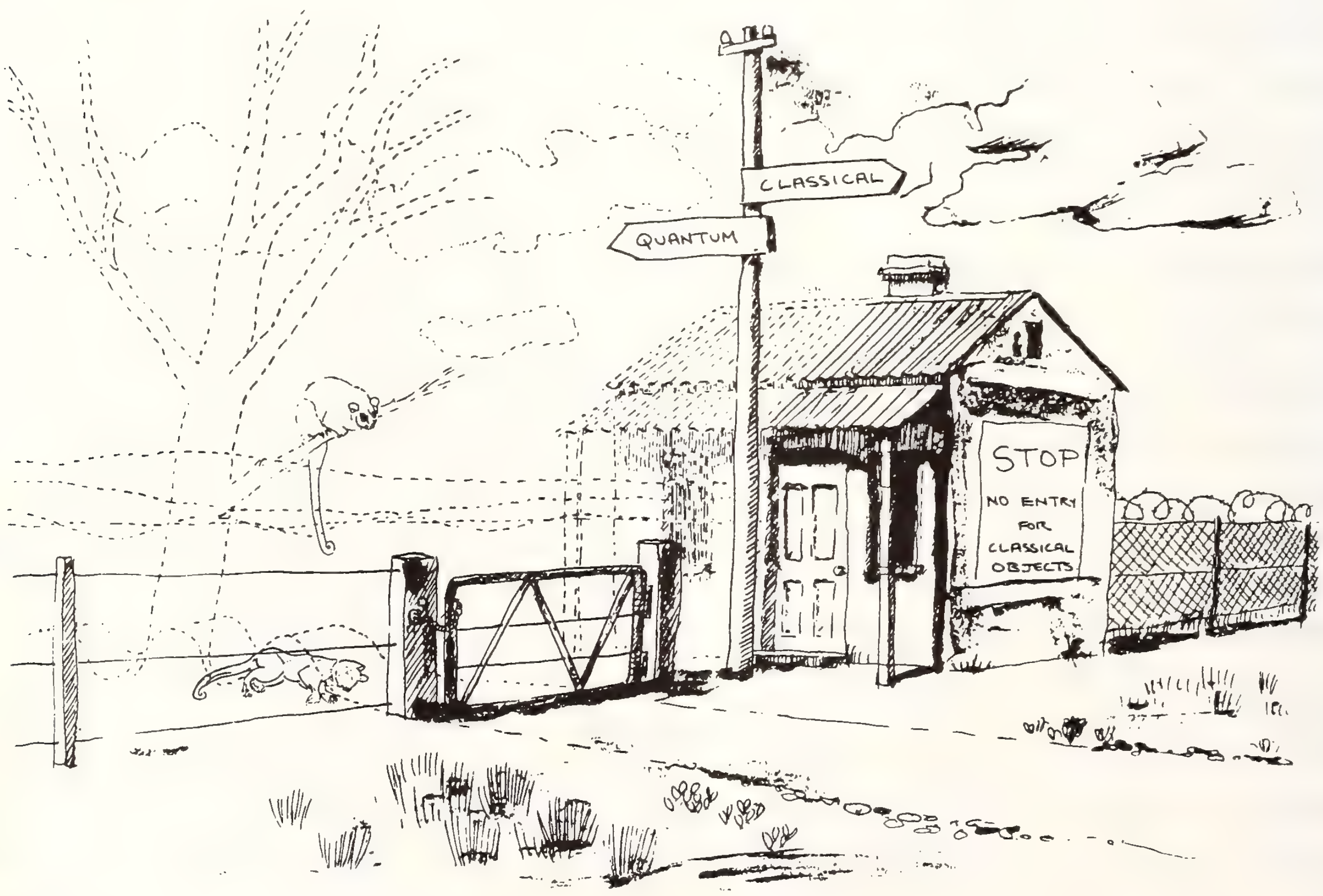

Figure 5. The cartoon illustrates the dilemma posed by the Copenhagen interpretation of quantum mechanics. It points up how arbitrary is the division assumed to demarcate the quantum world (of say atomic particles) with the classical world (of say measuring instruments).

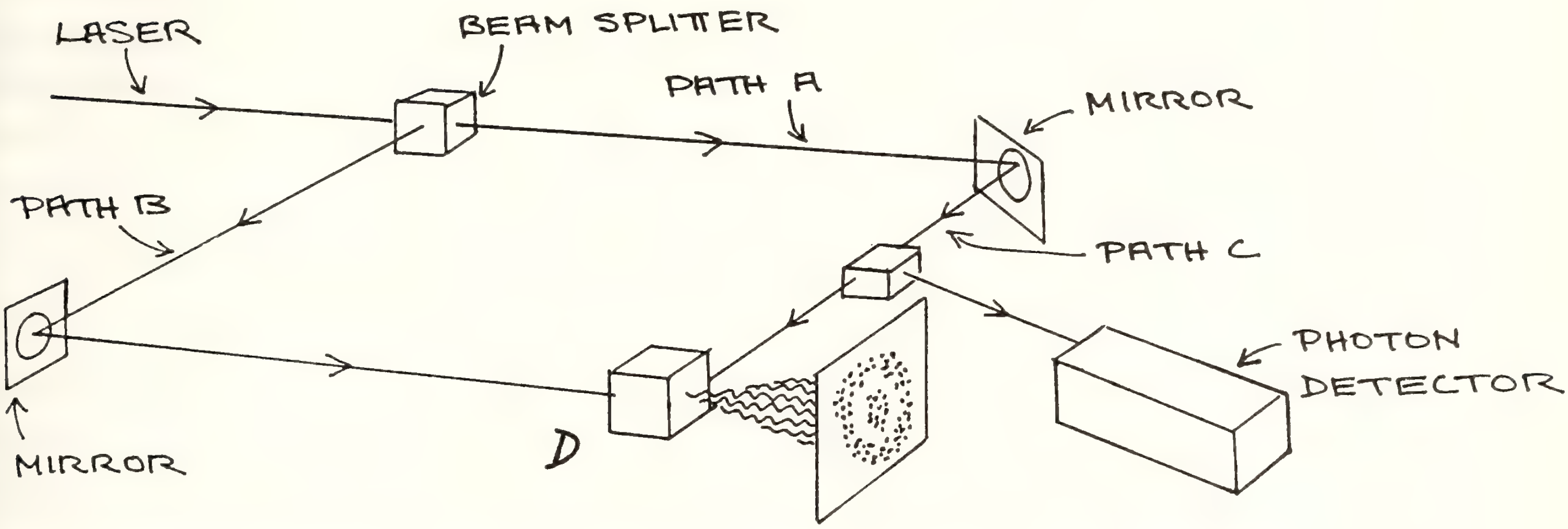

Figure 6. Bohm's interpretation of Schrodingers equation is illustrated by this experiment.

particle and is recorded as such by the photo-detector. In this interpretation of Schrodinger's equation there are no superimposed states that lead to the difficulties which arise in the Copenhagen School's ideas.

Schrodinger's cat escapes the dilemma of being neither dead nor alive in David Bohm's intepretation of how the Schrodinger wave equation should be applied in quantum mechanics. In this case the position of the electron on the scintillation screen, after it has passed through one of the two double slits, is not given by the superposition of states of the electron at different positions on the screen, so that the electron is not simultaneously at different sites before an observation is made . Rather the position of the electron on the screen is ascertained deterministic manner in the following way. The Schrodinger wave function of the electron splits up and passes through both slits in the screen, while the electron itself passes through one of the slits as a single particle must do. Which slit the electron passes through is deterministic, based simply on the initial position and initial wave function, according to the linear differential equations of motion. The two parts of the electron's wave function join on the other side of the double-slit screen, with the part of the wave function that did not take the same pathway as the electron itself interfering with the wave function that went with the electron. It is the interference of these two waves which then determines the position at which the electron hits the screen (the part of the wave function that did not go with the electron is not capable of conveying effects to any other particle). This deterministic procedure does not involve the metaphysical paradoxes which arise in the case of the Copenhagen Interpretation, with its superposition of different states. According to Bohm's theory the electron has either hit the middle of the screen or not, so that the cat is dead or alive before the observer looks in the box. The cat is not in a superposition of states in which it is neither dead or alive.

GELL MANN AND ZUREK'S INTERPRETATION OF SCHRODINGER'S WAVE EQUATION

Schrodinger's cat also escapes the dilemma of being neither dead or alive in the Gell Mann and Zurek interpretation of how Schrodinger's equation should be interpreted. In this case it is argued that the quantum-system residing in the Schrodinger cat cage is not a closed system, isolated from the environment even in the absence of an observer. Indeed no macroscopic system is isolated from its environment. This allows one to avoid the difficulty that the evolution of the deterministic linear Schrodinger wave equation of a system evolves into a state that simultaneously contains many possibilities which we never see to coexist, such as the cat being both dead and alive. The core problem is the principle of superposition that resides in Schrodinger's wave equation in contrast

to our common experience of a classical reality. Gell Mann and Zurek argue that while Wigner is correct in saying that the final point in the von Neumann chain resides in our consciousness of the world, that is we are conscious of only one of the superposition states given by the Schrodinger equation, it is very likely that the state is already chosen from amongst the superpositions before consciousness is involved at all. In the cases of Schrodinger's cat, the superpositions are destroyed by interaction between the quantum events in the cage and the environment, well before an observer looks in the cage. It is argued that the environment effectively makes a superselection which prevents certain superpositions from occurring, so that only states that survive this process become classical and so are observed. This is the reason why we perceive just one of the quantum alternatives. In a sense, the interaction of the quantum system with the environment involves a transfer of information from the quantum system to the environment. If an observer is present then such leakage of information from the quantum system will be to the brain of the observer, in this case constituting part of the environment. Indeed, quantum events in our own brains, say involving different quantum superpositions of the states of a neurone, will be lost very quickly compared with the times of biological process. This is due to information leaking from the neurone to the environment (in this case consisting of ions etc surrounding the neurone), leaving the neurone in a preferred classical state.

According to this scheme observers have lost their privileged position in monitoring a system involving the tranfer of information to a recording apparatus. Information is also transferred from the quantum system to other elements of the environment. The only difference between the two is the difficulty of decoding the information taken up by elements of the environment compared with that taken up by our specially designed observing apparatus. In the case of the two slit experiment, by the time the electron reaches the screen it will, under normal circumstances, have interacted with components of the environment that greatly decrease the probability that superimposed states will exist at the screen. Only definite states will exist, that is the electron will have hit the screen within one of the three regions shown in Figure 2B.

It is usually argued that the brain is too hot at body temperature to maintain the coherent states of superposition for a neurone which might arise from interference effects at the quantum level. Gell Man and Zurek contend that even if such interference effects exist, giving rise to coherent states of superposition, they will very quickly (compared with biological times) dissipate due to interactions between the neurone and its environment so removing all but one of the solutions to the Schrodinger equation.

THE CONCEPT OF NON-LOCAL REALITY IN QUANTUM MECHANICS.

All interpretations of quantum mechanics so far enumerated require the concept of non-local reality. In non-local reality an event that occurs in say region A can instantaneously have a physical effect in region B, independent of how far A is from B and of the conditions in the space between A and B. This is illustrated in Figure 7 by the following simple experiment. A source of photons is placed midway between two polarizing films which allow the passage of all photons that are linearly polarized along a horizontal axis; however they allow with decreasing probability the passage of photons that are linearly polarized at an angle q to the horizontal (where the probability is proportional to $\cos^2 q$). The source contains photons that each have a superposition of states in which they are linearly polarized along a horizontal axis and a vertical axis; in this case q is 45^0 so that $\cos^2 q = 0.5$ and there is a 50% probability that a photon will pass through the horizontally oriented polarizing film. If pairs of such correlated photons are simultaneously shot out of the source at both screens, then the expectation is that each should independently pass through with a 50% probability. Instead, what happens is that if one

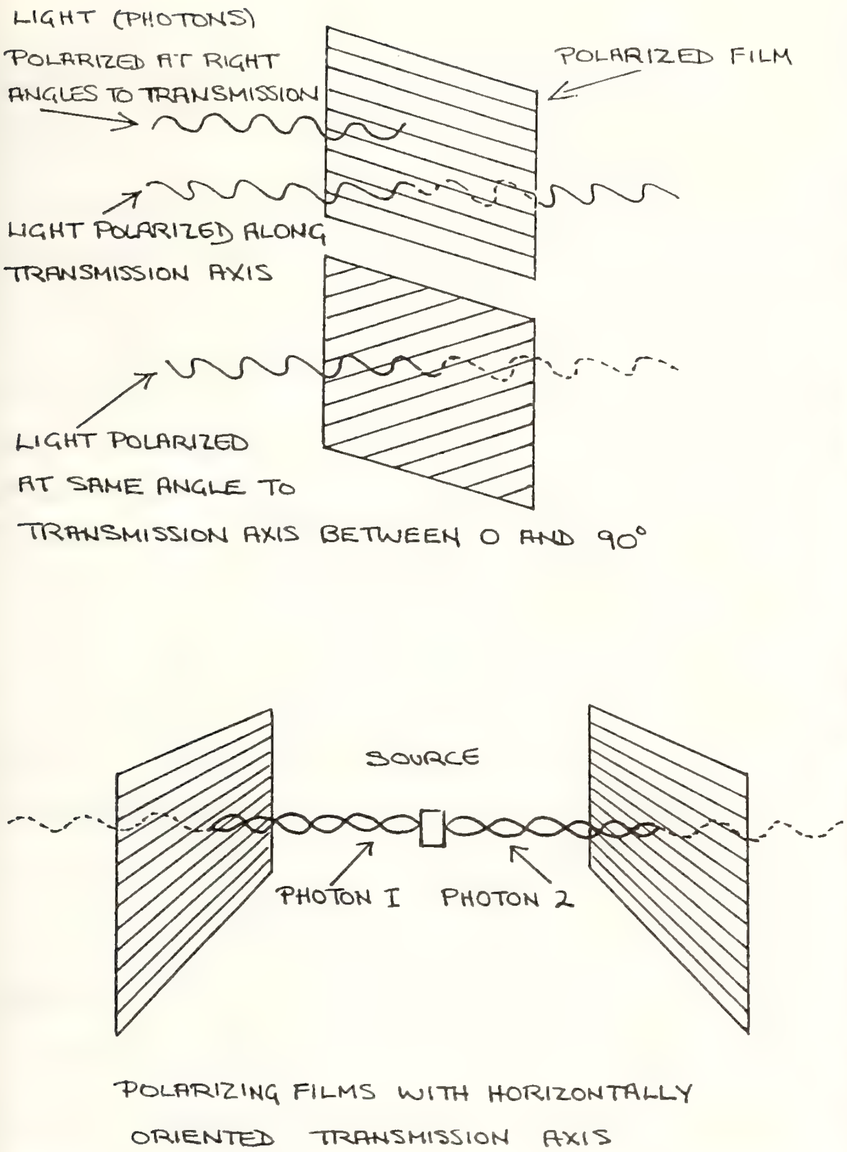

Figure 7. All interpretations of quantum mechanics involve the concept of non-local reality, which is illustrated by means of this experiment.

photon is transmitted so is the other and if one is blocked so is the other. The second photon of the pair knows what the other photon does even though they are well separated. There is instantaneous transmission of information from one photon to the other. The discovery that such correlated particles can affect each other over large distances independent of intervening space, amounts to a non-local interaction and is thus termed ‘non-local reality’.

It has been suggested by Penrose that an example of non-local reality at work can be observed in the assembly of quasi crystals. For instance the Al-Li-Cu alloy due to Gayle(1987) has a crystal symmetry that apparently can only be assembled by using non-local ordering of the atoms. In this case, to assemble such a crystal requires that the pattern of atoms some distance from the region of assembly be determined in order to avoid errors in the arrangement of atoms gathered up at the point of assembly. This could be done by a mechanism of non-local reality, as described in Figure 7.

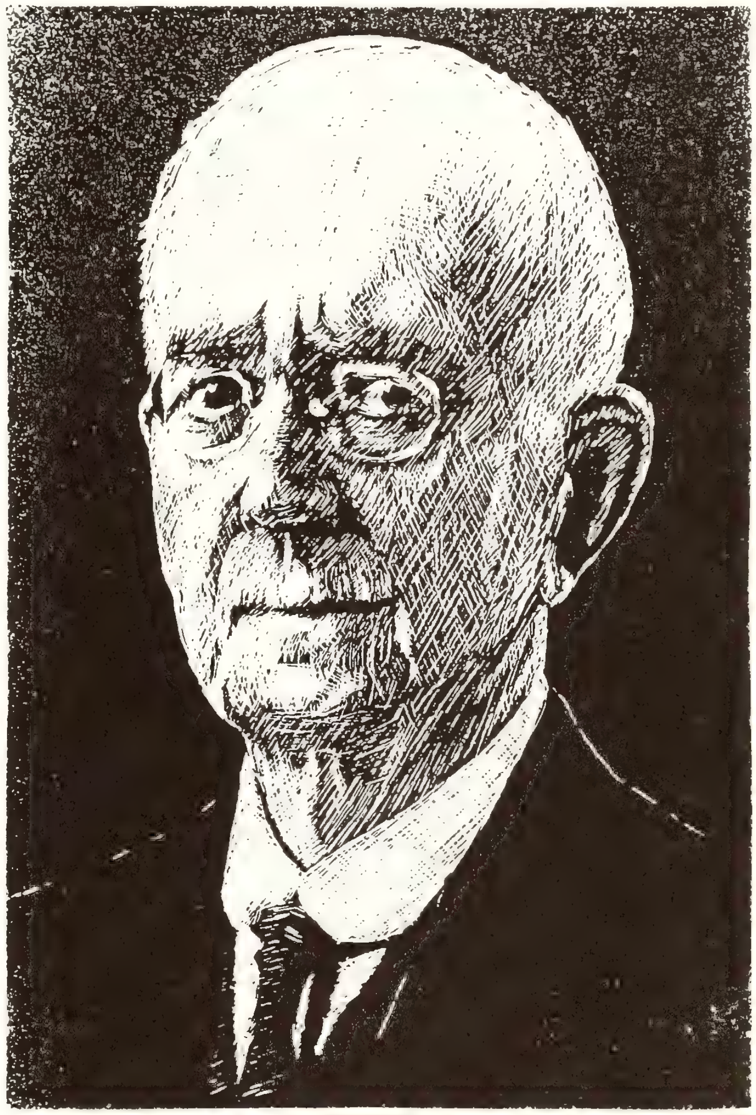

Figure 8. C.S. Sherrington (1858-1952).

IDEAS CONCERNING THE OPERATION OF NON-LOCAL REALITY IN THE BRAIN: THE ORIGINS OF CONSCIOUSNESS?

Beck and Eccles (1992) believe that nerve terminals may be considered to have a crystal-like structure, so that non-local phenomenon occur by quantum mechanical means at these terminals. The physical structure of nerve terminals and of the site where they attach to the surface of neurones was first given emphasis by Sherrington (Figure 8), the founder of neuroscience, and called by him 'the synapse'. Synapses form all over the surface of neurones, as is illustrated in Figure 9 by

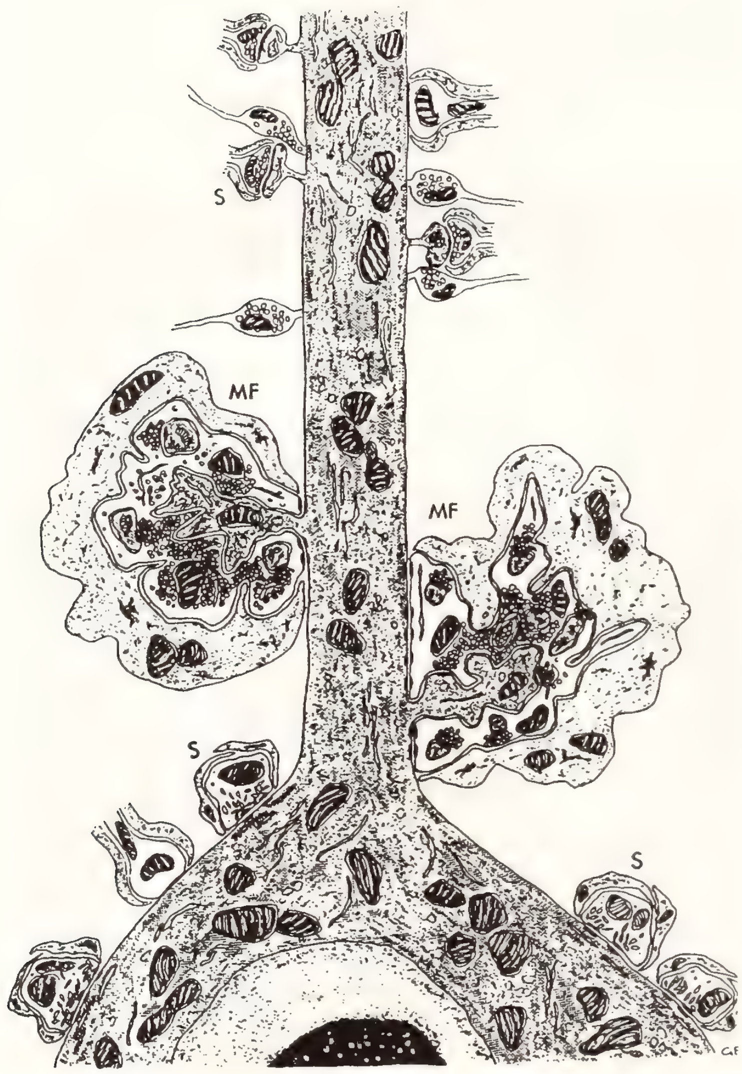

Figure 9. A neurone from the CA3 region of the hippocampus together with synapses on its round cell body as well as on the large dendritic shafts.

considering a neurone from the memory region of the brain called the hippocampus: this neurone has synapses (S) on its round cell body as well as on the large dendritic shafts; the largest synapse in the brain, formed by the so-called mossy fibre synapses (MF), are also illustrated. The class of large neurones in the brain are called pyramidal cells, and each may possess up to 30,000 synapses on their surface. Synaptic terminals also form on neurones in the thalamus, which is the part of the brain concerned with passing sensory information, such as that involved in vision, to the neocortex from the sensory receptors, such as the photoreceptors in the eye. Figure 10 shows a single dendritic shaft (relatively dark) of a thalamic neurone which gives off a spine-like protrusion. This spine has four synaptic boutons (relatively pale) impinging on it and these can be identified by the collection of small vesicles crowded together in each bouton as well as by the dark bars in the spine which underly the collection of vesicles. Some of the synaptic boutons also receive synapses on their membranes. The small vesicles contain transmitter substances which, if released from the bouton, diffuse onto the membrane of the neurone, and transiently bind to it, therebye increasing or decreasing the electrical excitability of the neurone.

A synaptic bouton may then have a paracrystalline structure which requires Schrodinger's equation to describe its quantum states. The membrane of the synaptic bouton immediately impinging on a neurone soma (see Figure 10) or dendrite (see Figures 9 and 10) possesses dense projections (dp) with the dimensions shown in Figure 11. These dense projections constitute what is called the active zone of the bouton. The synaptic vesicles (SV) insert between the projections of the active zone. It is hypothesized that following arrival of a nerve impulse in the bouton a single vesicle on the active zone may release its contents by the method of exocytosis. Other vesicles (about 50 to 100 on the zone) are prevented from releasing because the hypothesized paracrystalline array of the active zone possess components that are in a state of quantal coherence enabling non-local instantaneous interactions of different parts of the active zone. Once a vesicle, interacting with the active zone, is irretrievably committed to the release of its transmitter then this information is conveyed instantaneously to the rest of the active zone, producing non-local changes in the paracrystalline array that prevent other vesicles from releasing transmitter.

Non-local reality may arise in a different way in the brain through quantum correlations involving phonons, as first suggested by Frolich

Figure 10. Synaptic terminals formed on a neurone in the thalamus.

(1968). Phonons stand in relation to the electrical vibration of matter (say a dipole molecule) in an analogous way to photons and oscillations of the electromagnetic field. Phonons can be thought of as particles then in the same way as photons and so are subject to quantum mechanical effects in the same way as photons. How may phonons be used by neurones? One possibility involves consideration of the way in which the proteins in the membrane of neurones, that are responsible for the movement of ions between the inside and outside of the neurone, interact with the intracellular skeleton of the neurone.The components of these membrane proteins may be considered to be dipole molecules that give rise to phonons. If the rate of energy supply to these oscillating dipoles from the cytoskeleton is sufficiently high a fraction of the energy is not lost to the elements that make up the constant temperature heat bath surrounding these membrane proteins, such as ions moving in the solutions on either side of the neurones membrans. This energy fraction may then be stored in such a way as to create phase and amplitude correlations between the phonons of the system over very large distances. In other words the energy fraction is stored in the phonons of the system and may be used to create new phonons. Quantum correlations arise between the phonons in this way so that coherent superpositions occur in the system of phonons over large distances. Frohlich (1968, 1986) and Marshall (1989) have argued that quantum correlations between phonons of the neurone membrane channel proteins responsible for the excitability of the neurons could arise over large distances in the nervous system.

Non-local reality, however it arises, has been suggested by Penrose (1987) to mediate the holistic experiences of consciousness that involve correlations between near simultaneous events at large distances apart in the neocortex. Such events may involve identification of an object in the inferior temporal cortex with determination of its movement in parietal cortex, many centimetres away. These quantum correlations over extensive distances may then be responsible for the coherence of conscious experience involving many of the brains parallel processing neuronal units spread throughout the neocortex.

The possibility that quantum mechanical ideas, which are so removed from 'commonsense', will be required to explain some aspect of synaptic or neuronal function is still open. Although at present this is not the case, we are still at such a profound level of ignorance concerning synaptic, neuronal and brain function that it would be very premature to say the case is closed for quantum mechanical explanations of consciousness. The high temperature of the brain would seem to be a large obstacle for the emergence of any states of

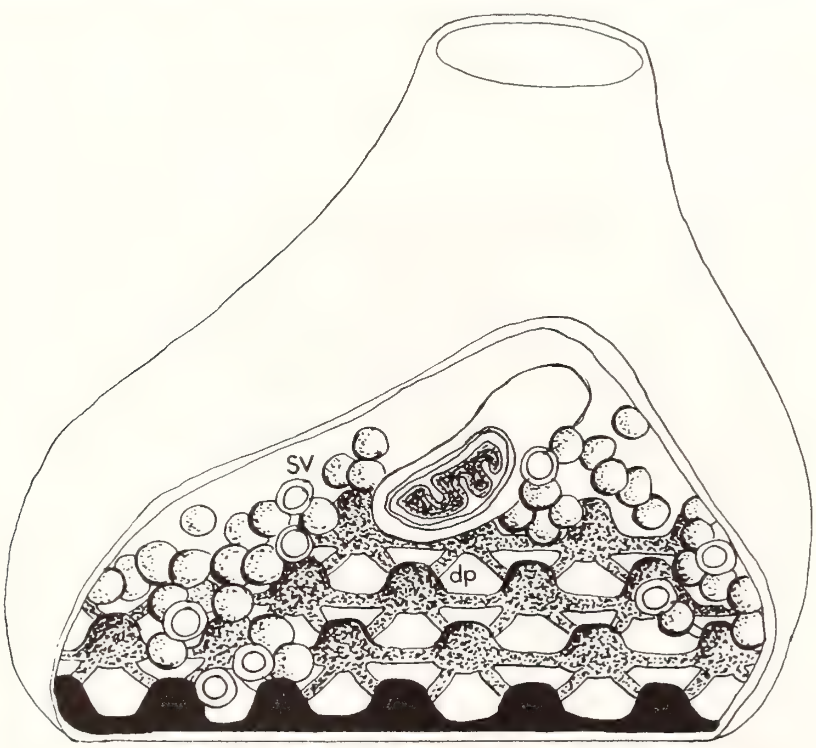

Figure 11. A synaptic bouton may have a paracrystalline structure which requires Schrodinger's equation to describe its quantum states.

quantum coherence. However the recent success in obtaining superconductivity at relatively high temperatures, involving as it does quantum mechanical effects, does suggest that even the temperature problem may not be an insurmountable obstacle. It may well be that the weird world of the quantum does include our consciousness.

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MASTERS THESIS ABSTRACT

Towards a Crop Growth, Development, and Yield Model for *Lupinus angustifolius* (Narrow Leafed lupin) in Tasmania

Andrew C. Bishop, B.App.Sc

Experiments were conducted between 1988 and 1990 at Elliott, Cressy, and Ross in Tasmania using three cultivars (Yandee, Geebung, and 75A329) of narrow-leafed lupin (*Lupinus angustifolius*). The purpose of these experiments was to examine narrow-leafed lupin growth and development in Tasmania in relation to specific environmental factors. These factors were related to growth and development measurements. It was hoped to use these relationships in a simple crop model suitable for assessing sites for the commercial production of lupins.

Preliminary experiments in 1988 examined the lupin cultivars for agronomic suitability in Tasmania. Increased grain yield was a function of more pods/m^2 rather than increased pods/plant. This suggested that lower yields of the indeterminate line 75A329 could be compensated for by a higher plant density than in the indeterminate cultivars. Lupins responded to higher rainfall and extended growing season at Elliott thus outyielding crops at Cressy and Ross.

Detailed field experiments were conducted in 1989 and 1990 at Elliott and Cressy. Lupin crops developed very slowly in the first 8-10 weeks, and then grew rapidly after flowering was initiated. It appeared floral initiation was a function of higher temperatures and longer days in Yandee and 75A329, with further responses to vernalisation in Geebung.

Plant density significantly affected grain yield. 75A329 showed the largest yield responses to increased plant density. Although increased plant density resulted in increased leaf area, leaf senescence took place earlier in the highest density crops probably due to competitive effects. Optimum density for the indeterminate cultivars was 40 plants/m^2. It may be higher for determinate cultivars. Low density crops were able to utilise their leaf area for light interception more efficiently than high density crops. In the latter, branches and leaves were pushed more towards vertical rather than horizontal thus less leaf area was presented to intercept light.

The study established that early sowing of lupins in Tasmania allows more time to grow and develop and yield more grain. A direct relationship was established between increased total dry matter and increased grain yield.

The model developed in this study used thermal time as its only external factor to determine L, intercepted radiation (%), and total dry matter (kg/ha) during crop growth. From the predicted figure for total dry matter accumulated by harvest time, an estimate of potential grain yield could be made for that crop.

This study demonstrated the principle of collecting agronomic data and, guided by basic plant physiological principles and mathematical procedures, assembling simple sub-models that when linked can approximate a particular aspect of crop growth.

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DOCTORAL THESIS ABSTRACT

The Twenty-Four Caprices of Niccolo Paganini
Their significance for the history of violin playing and the music of the Romantic era

Philippe Borer

This project attempts to describe and elucidate the compositional and instrumental character of the twenty-four Caprices of Niccolo Paganini and their far-reaching influence on violin playing and on musical creativity up to the present time. There is also the wider inspirational value which can be traced in literature, poetry and fine arts.

The first chapter aims to place the twenty-Four Caprices in their historical perspective. The reception accorded to the work by prominent musicians of the time (in particular Chopin, Liszt and Schumann) whose attention was drawn to the concept of virtuosity as an essential parameter in musical composition is examined.

Chapter 2 investigates the unique significance of the dedication "alli Artisti" which suggests a Romantic *manifesto* some ten years before Hugo's prefaces to *Cromwell* and to the *Eastern Lyrics.*

Chapter 3 investigates Paganini's instrumental and musical background. It has often been claimed that Paganini was self-taught. however, evidence of his all-important early training in violin and composition makes him the true heir of the old Italian masters, representing at the same time a vital milestone for subsequent development of instrumental and compositional techniques. Paganini can thus be seen as representing a link between the classico-romantic and modern attitudes to instrumental writing, reaching well into the twentieth century.

In Chapter 4, some aspects of Paganini's compositional and performing styles are examined. a striking interpretative concept (the "suonare parlante") is discussed. special consideration is given to instrumental techniques which are not employed in the Caprices. Their absence suggests that the Caprices represent a perhaps intentionally restrained statement of Paganini's violinistic knowledge.

Chapter 5 traces the origins of the violin Caprice and its development as a musical genre.

The appendices include an analysis of selected Caprices, a diplomatic transcript of Caprices 1-4, a facsimile of the manuscript, as well as supporting documents such as *Feuilles d'album* and scales written by Paganini.

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DOCTORAL THESIS ABSTRACT

The Making of an alienated Generation

LEUNG Sai-wing

In this thesis, we argue that the four presuppositions of the consensus model of political socialisation are empirically unfounded. Neither are Marxist approaches to political socialisation supported by empirical evidence. We thus propose our dissensus model of political socialisation: due to process variation, life cycle variation, generation variation, and social variation, the outcome of political socialisation could be dissensus. likewise. socialisation of alienation is as equally possible as socialisation of allegiance. The so-called socialisation of alienation, our theoretical framework, refers to the accentuation of the socialisation process by political events such that people are sensitised to political reality and thus feel alienated.

From an historical review of political socialisation in Hong Kong in the past four decades, we found that because of the immigrant nature of Hong Kong population, there was an anti-Communist china sentiment which was kindled by a series of political confrontations between the Chinese Government, the Hong Kong Government and local Chinese during the transition of Hong Kong from a British colony to a Special Administrative Region (SAR) Government under the sovereignty of China. Growing up in this turbulent transitional period, the young generation of Hong Kong has been socialised to be alienated to the Chinese Government. to study this process, we conducted a case study of a secondary schooll (including interviews with the teachers and students), a society-wide survey of secondary school students, and a mail questionnaire survey of sampled school teachers in 1988 and obtained four data sets.

On the basis of analysing these four data sets, we found that there was a benevolent image of the Hong Kong Government but a malevolent image of the Chinese Government. However, the event effect on the socialisation of alienation was only salient in a subsample, which thought the most important contrast between Hong Kong and China was the market system, but not visible in three other subsamples. There were hints that students might be socialised to be alienated by parents and stereotyping. Because of the depoliticisation and trivialisation of civic education in secondary schools, we found that secondary school students were not implanted with any political identity. Interestingly, in the "market system" subsample, more civic education helped to heighten the alienation from the Chinese Government. We found also that a prestige school environment, a secondary education, and the school subject "Government and Public Affairs", are three salient factors in producing political alienation. From the eight strata of our sample, we found that the most alienated group of students were Form 7 arts students from symmetrical schools.

The widespread alienation from the Chinese Government was found to be related to students' pessimistic view of Hong Kong" future, an atrophying sense of political community (more opted for migration and took an apathetic attitude towards future political participation), and a rising sense of localism (more identified with Hong Kong and rejected Chinese officials taking up positions in both the public and private sectors of Hong Kong). After the June 4th 1989 Incident, this widespread alienation must be fuelled to the extent that the legitimacy of the SAR government and the political identity of the younger generation of Hong Kong would be in doubt.

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DOCTORAL THESIS ABSTRACT

Reproductive Biology in relation to phylogeny of the Orchidaceae, especially the tribe Diurideae.

Mark Alwin Clements

Aspects of the biology of representatives of the so-called "primitive" members of the family Orchidaceae, especially the fundamentally Diurideae (subfamily Orchidoideae), were studied to determine and characterise developmental patterns and to enunciate phylogenetic relationships between these taxa. Representatives of the closely related families Alstoemeriaceae, Asphodelaceae, Burmannia Haemodoraceae, Hypoxidaceae and Iridaceae were also studied for comparative purposes. Early reproductive tissue development was studied in c. 360 species using freshly collected material of anthers or ovaries, cleared in lacto-phenol and examined either on a Nikon Opiphot-pol or Confocal scanning laser microscope. Images were captured and stored digitally on disc. When fresh material was unavailable, ovaries sampled from dried herbarium specimens and reconstituted in ammonia solution or lacto-phenol, provided sufficient detail to determine general embryological developmental patterns.

Microsporogenesis and microgametogenesis are very uniform throughout most "primitive" orchids and conform to that reported for most other monocotyledons. Microspores mature in tetrads with the exception of *Apostasia, Neuwiedia* (subfamily Apostasioideae) and certain members of the subfamily Cypripedioideae which form monads. The microspore monads so formed are relatively uniform in shape whereas those that result from the later breakdown of a mature tetrad are irregular in shape.

For the majority of study taxa including all taxa studied in the tribe Diurideae, megasporogenesis and megagametogenesis are characterised as being anatropous, tenuinucellate, with monosporic megaspores that generate Polygonum-type embryo sacs with a bitegmic condition. In the case of *Apostasia, Neuwiedia* and members of the Cypripedioideae, megasporogenesis is the bisporic type and megagametogenesis results in an Allium-type embryo sac. The unitegmic condition was only found in *Epipogium* and *Spiculaea.*

Embryogenesis in the "primitive" orchids, conforms to recognisable developmental patterns characterised by the presence or absence of a suspensor, position (internal or external to the embryo sac), its structure (number of cells, whether in a linear row or as a multiple group of cells) and the origin of cells in the embryo proper (apical cell or apical and basal). Endosperm development was not observed in any orchids. When present, the suspensor appears to aid in the transfer of nutrients from cells of the outer integument which becomes vacuolated as the embryo reaches maturity. Lipids and other storage bodies were observed in cells of the embryo proper from an early stage of proembryo development. Apomixix and polyembryony were observed in some taxa.

Seven fundamental embryo patterns were identified within the "primitive" orchids, termed the Cyripedioid, Vanilloid, Epidendroid, Cymbidioid, Nettioid, Spiranthoid and Orchidoid embryo patterns. The Cyripedioid pattern is present in *Apostasia, Neuwiedia, Paphiopedium, Cypripedium, Phragmipedium, Tropidia, Epipactis, Cephalanthera* and *Gastodia.* The Vanilloid pattern occurs in *Vanilla, Eriaxis* and *Erythrorchis.* The Epidendroid occurs in *Cattleya* and *Encyclia.* The Cymbidioid pattern exists in *Bletilla, Cymbidium, Dipodium, Eulophia* and *Grammatophyllum.* The Neottioid pattern is restricted to *Neottia* and *Listera.* Three embryo types exist within the Orchideae, Diurid and *Townsonia* types, these being differentiated by the number of cells present in the suspensor: four to eight in the Orchideae; one or

occasionally two in the Diurids and none in the *Townsonia*. The Orchideae type is present in both the tribes Diseae and Orchideae. The Diurid type embryo is present in the majority of genera traditionally treated as part of the tribe Diurideae, except for *Chloraea, Bipinnula, Geoblasta* and *Gavilea* and the Pterostylidinae which have a Spiranthoid embryo pattern. The *Townsonia* type is found exclusively in that genus. The Spiranthoid embryo pattern also occurs in the tribes Spiranthinae and Goodyerinae.

Embryogenesis in Orchidaceae differs from that found in *Burmannia, Hypoxis, Alstroemeria* and *Tribonanthes*, mainly by the lack of endosperm and possession of vascularisation in the funiculus.

The ontogeny of the protocorm-seedlings was studied in approximately 260 species, representative of most major taxonomic groups within the Orchidaceae. Eleven basic categories were identified and named, based on gross morphological features, viz. obovoid, obovoid-deorsum, elongate, reptant, discoid, bracteate, rhizomatous, callus, isobilateral, echinate and globular.

Broad (family) and narrow (subfamily and below) based cladistic analyses were undertaken to determine phylogenetic relationships between these taxa. Characters and states were based on studies of the floral and vegetative morphology of fresh material, developmental embryological data and protocorm-seedling morphology. The inclusion of developmental embryological data proved significant in resolving the phylogenetic relationships.

At the broad level, the Orchidaceae, with *Apostasia, Neuwiedia* and the Cypripedioideae included, is unequivocally shown to be monophyletic based on possession of five synapomorphies; (i) partially or fully fused style and filaments to form a column; (ii) lacking an endosperm; (iii) an undifferentiated embryo; (iv) a protocorm; and (v) lacking vascularisation of the funiculus.

At the narrow level, subfamily Orchidoideae is monophyletic when the Spiranthinae, Goodyerinae and Pachyplectroninae are included along with the Orchideae (Orchideae, Diseae), Diurid (Diuridinae, Acanthinae and Caladeniinae) and Cryptostylid (Cryptostylidinae, *Rimacola, Megastylis*) clades. Thus the subfamily Spiranthoideae is taxonomically superfluous. The Diurideae is monophyletic with the removal of the Pterostylidinae and the Chloraeinae (to the Spiranthoid clade) and *Rimacola* and *Megastylis* to the Cryptostylid clade. a new classification of the subfamily is proposed based on these results.

The Cypripedoid embryo pattern is common to all basic taxa and it is therefore considered the plesiomorphous state for this character. The rhizomatous type protocorm-seedling development is also considered the likely plesiomorphous state for the family. The interpretation of this character and number of fertile anthers in the orchid flower, is re-evaluated based on the results of these cladistic analyses.

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DOCTORAL THESIS ABSTRACT

A contrastive analysis of English and Persian intonation patterns

A. Majid Hayati

The contrastive analysis (Ca) hypothesis attempts to predict the areas of difficulty which learners of a second/foreign language will encounter. It has been the subject of debate among linguists for a long time.

The arguments advanced by the researchers in the field have produced three different versions of the CA hypothesis: strong, weak and moderate. All assume the importance of interference phenomenon but each approaches it from a different viewpoint. however, in all versions, there seems to be argument on two important aspects of the CA hypothesis:

a. degree of similarity corresponds to degree of simplicity

b. degree of difference corresponds to degree difficulty

In the context of this hypothesis, the present study has compared and contrasted the intonation patterns of English and Persian. This research has two primary objectives:

a. As far as I am aware, there has been no comprehensive comparative study of English and Persian intonation patterns, particularly with the aim of identifying possible pedagogical implications. Consequently, the first objective is to present to Iranian teachers of English a set of general ideas about the possible problems that Persian learners of English may face in the process of language learning. The present contrastive analysis will, I hope, be beneficial to language teachers, curriculum designers, and material developers to use in their class activities and overall plans.

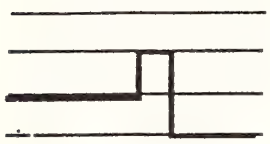
b. The second objective is to evaluate and reformulate the hypothesis. to this end, an experiment involving ten Iranian students studying at the University of Wollongong was conducted. The subjects were of approximately the same level of proficiency as determined by the scores they had achieved at the end of a three-month English course.

Approximately sixty out of-of-context sentences of different types were given to the subjects to read. Their readings were recorded by a high-quality tape-recorder. These were then presented to three native speakers of Australian English (two linguists and a postgraduate student majoring in English Literature) who were asked to describe the intonation patterns. An American native speaker (a linguist) was asked to read the same sentences and then his reading was used as a model to measure the rise and fall of the intonation. Analysis of the data revealed that although the sentence-final intonation patterns are similar, the subjects nevertheless had problems using the correct English intonation over the whole structure because they attempted to put the primary stress on words partly according to the stress system of their own language. In fact they made very few mistakes in producing the correct sentence-final intonation pattern of English.

The experiment showed the need to take stress patterns into account since they are an integral and significant feature in determining the rise and fall of the pitch contours. Since the stress placement system is different in English and Persian, the intonation pattern of the two languages will also be different. This is illustrated by the following examples from English and Persian:

Persian:
maen **ne**-mi-tun-aem be-raem?unja.
/Sub Neg-Vpr-can-pp Vpr-go Adv/

English:
I can't **go** there.



(Abbreviations used in the Persian sentence are as follows: Sub=subject, Neg=negative marker, Vpr=verb prefix, pp=personal pronoun, Adv.=adverb.)

If we only consider the sentence-final position, where the final intonation change occurs, that aspect of the hypothesis that similarities present no difficulties to the learners is supported because the sentence-final intonation patterns of the two languages are quite similar (falling in statements and wh-questions, rising in yes/no questions, etc.)

A look at the above examples reveals that in the Persian sentence, the negative marker, "**ne**", receives the primary stress and causes a rising tone on the same constituent; but, it is different in English: the change of tone normally close to the end of the sentence where "go" as the content word carries the strongest stress.

Comparing the results of the experiment with the predictions, it was concluded that three out of the four predictions were in fact confirmed. Moreover, that part of the hypothesis suggesting the relation between difference and difficulty was partially (at most in negative sentences) confirmed. In regard to wh-questions, however, the results did not match the predictions.

This suggests that in contrastive analyses of the intonation pattern of any two languages it is important that the analyst consider the entire sentence as the domain of the intonation contour. Secondly, since some predictions were not confirmed, a reformulation of the contrastive analysis hypothesis which required consideration of levels of similarity and difference was suggested.

Finally, the study reveals the need to take both similarities and differences into account in treating students' problems in using English intonation. for intonation is a suprasegmental phenomenon and requires that the learner have sufficient command of the elements affecting the tone variations.

This is not, however, best acquired from formal explanations of the nature of intonation of the two languages. Instead, depending on the student's level of proficiency, the whole process of teaching intonation may start with pure imitation of a model (preferably a native speaker's voice on a tape-recorder) and end with free communication. In the meantime, using gestures to show the rise and/or fall of voice can be of great benefit to teachers of English.

The study provides a more adequate basis for teaching intonation patterns and identifies one source of interference from another phonological process (stress placement) which at the first glance might appear to be not directly related to intonation.

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Annual Report of Council

for the year ended 31st March, 1996

PATRON.

On retiring from the Office of Governor-General of Australia His Excellency the Governor-General Mr. Bill Hayden expressed his pleasure at having been associated with the Society and extended his best wishes for the future. The Council wishes to express its gratitude to His Excellency Rear Admiral Peter Sinclair AC, Governor of New South Wales for his continuing support as Patron of the Society during his term of office which ended in February 1996. The Council wishes to welcome the incoming Governor of New South Wales, His Excellency the Honourable Gordon Samuels AC and thank His Excellency for graciously granting Vice-Regal patronage to the Society.

MEETINGS

Eight General Monthly Meetings and the 128th Annual General Meeting were held during the year. The Annual General Meeting and seven of the General Monthly Meetings were held at the Australian Museum and one (October) at the University of Western Sydney. A summary of Proceedings is set out below.

SPECIAL MEETINGS AND EVENTS IN 1995/96:

April 29th, 1995, The outgoing President Mr. J.R. Hardie, the Hon. Secretary (Ed.), Mrs M. Krysko v. Tryst, the Vice-President Dr. E.C. Potter and Mrs. Potter accepted an invitation from the Council of Sutherland Shire to represent the Society at the 225th Anniversary Commemoration of the Landing of Captain James Cook, RN, at Kurnell (Sydney) on 29 April 1770.

August 19th, 1995: Dr. D.F. Branagan and Dr. H.C. Cairns led a Field Meeting to the Ku-ring-gai National Park to examine aboriginal and other markings on rock surfaces. About 15 members and visitors attended.

October 11th, 1995 The 48th Clarke Memorial Lecture (1995) was delivered by Dr. Ross Taylor, Research School of Physical Sciences, The Australian National University, Canberra, at Macquarie University, North Ryde NSW. The lecture, seen as a celebration of the Moon Landing, was entitled "Recent Developments in Planetary Research". A vote of thanks was offered by Dr. D.J. Swaine.

November 18th 1995: a meeting commemorating Professor Rontgen's discovery of X-rays in 1895 was arranged by Dr. G.C. Lowenthal and held at the Square House, University of New South Wales, Kensington NSW. Six speakers addressed an audience of about 35 persons.

February 13th 1996 The Society was co-sponsor of a Joint Meeting with four other societies:- The Australian Institute of Energy (Sydney), the Australian Nuclear Association, The Institution of Engineers (Australia) and The Nuclear Engineering Panel. The meeting took place at the Stephen Roberts Theatre, The University of Sydney.

Dr. David Mills, Research Fellow, Dept. of Applied Physics, University of Sydney, delivered the Pollock Memorial Lecture for 1995 entitled:- "Full Circle:- The Resurgence of the Solar Economy". Dr. E.C. Potter offered a vote of thanks. About 150 members and visitors attended.

March 13th 1996 The Society's Annual Dinner was held at the University of Sydney Staff Club, MacCallum Building. The Guest of Honour was Emeritus Professor Richard L. Stanton AO, from Armidale, NSW, who presented an after dinner address.

MEETINGS OF COUNCIL

Council held 10 ordinary meetings at the Society's office at North Ryde NSW.

Attendance was as follows: Dr. R.S. Bhathal (2), Dr. D.F. Branagan (9), Miss P.M. Callaghan (10), Dr. R.R. Coenraads (4), Dr. A.A. Day (10), Mr. G.W.K. Ford (10), Mr. J.R. Hardie (5), Mrs. M. Krysko v. Tryst (10), Dr. G.C. Lowenthal (8), Prof. J.H. Loxton (2), Dr. D.J. O'Connor (8), Dr. E.C. Potter (9), Dr. D.J. Swaine (9), Prof. W.E. Smith (9), Dr. F.L. Sutherland (7), Prof. W.J. Vagg (0), A/Prof. D.E. Winch (3). In July A/Prof. Winch resigned as Hon. Treasurer and Dr. D.J. O'Connor took over.

PUBLICATIONS

Volume 128, Parts 1, 2, 3 and 4 of the *Journal and Proceedings* were published during the year. They incorporated seven papers including the 29th Liversidge Research Lecture 1994, papers delivered during a Seminar "A Century of X-Rays", one discussion paper and one book review. Eleven abstracts of post-graduate theses as well as Biographical Memoirs, a current Membership List, a list of officers of the Society 1950-1995 and the Annual Report of Council for 1994-95 were published in this volume. Council wishes to thank all the voluntary referees who assessed papers offered for publication. Nine issues of the Society's Bulletin (Nos 185-193) were published during the year and Council thanks the various authors of short articles for their contribution. Sincere thanks go also to Mr. O'Keeffe who was instrumental in the publication of the Bulletin. Council received several applications to reproduce material from the *Journal and Proceedings*.

AWARDS

The following awards were made for 1995:

CLARKE MEDAL (in Geology): Professor Christopher McA. Powell (University of Western Australia, Perth W.A.)

EDGEWORTH DAVID MEDAL (research worker under 35 years of age): Dr. Anthony B. Murphy Acting Chief, CSIRO Div. of Applied Physics, Lindfield NSW).

THE SOCIETY'S MEDAL (for scientific research and service to the Society) Dr. Gerhard C. Lowenthal (University of New South Wales and Prince Alfred Hospital, Nuclear Medicine).

WALTER BURFITT PRIZE (for scientific work done in Australia or New Zealand): Dr. Richard M. Manchester (Director, Australian Telescope National Facility, CSIRO, Epping NSW).

The James Cook Medal and the Archibald D. Olle Prize were not awarded for 1995.

MEMBERSHIP

The membership of the Society at 31st March 1996 was: Patrons 2, Honorary Members 16, Members 262, Associates, Spouse Members 22.

During the year, Emeritus Professor Di Yerbury, AM, and Dr. Ken McCracken, AO, FAA, FTS, were elected Honorary Members.

The deaths of the following members were announced with regret:

Dr Viktor KASTALSKY, on 30 March 1995.

Professor Alan Heywood VOISEY, on 15 April 1995.

Norman James WARD, on 18 June 1995.

Eldred George BISHOP, on 8 August 1995.

Thomas Baikie SWANSON, on 18 August 1995.

Professor Stanley Keith RUNCORN, Honorary Member, on 5 December 1995

Professor Arthur John BIRCH, Honorary Member, on 8 December, 1995.

A List of Members was published in the *Journal and Proceedings*, Vol. 128 parts 3 & 4.

OFFICE

The Society continued during the year to lease for its Office and Library a half share of Convocation House, 134 Herring Road, North Ryde, on the southeastern edge of the Macquarie University Campus.

The Council is grateful to the University for allowing it to continue leasing the premises. Council greatly appreciates the secretarial assistance rendered by Mrs. V. Chandler during the past year.

SUMMER SCHOOL

A Summer School on computer science was planned but cancelled due to low enrolments.

LIBRARY REPORT FOR 1995/1996

As in previous years, acquisition of literature (usually journals) by gift and exchange has been maintained. The exchange & gift agreements are arranged and monitored at the Head Office of the Society in North Ryde, Sydney. Material from overseas and some Australian literature are sent directly to the Dixson Library at the University of New England. Other Australian material is received and added to the collection at Head Office of the Society.. Changes of address of foreign material received in the Dixson Library must be noted and communicated to the Hon. Librarian at Head Office, to ensure exchange agreements are in order. Council thanks Mr. Karl Schmude University Librarian, University of New England, and his staff - particularly Mrs. Helen Stokes for their continuing efficient care and responsibility in maintaining the processing and availability of the Royal Society Collection in the Dixson Library.

NEW ENGLAND BRANCH REPORT FOR 1995/96

The Branch held the following meetings during 1995: Wednesday, 14th June 1995: Professor Lesley Rogers and Dr Gisela Kaplan presented jointly some of the results of their recent observations on orang-utans in Borneo under the title "Orangutan Behaviour in the Natural Environment". The speakers provided the following notes: "Until recently, studies on the behaviour of apes tended to concentrate on group-living species such as the chimpanzee (*Pan troglodyte*) and the gorilla (*Gorilla gorilla*). The relatively solitary orang-utan (*Pongo pygmaeus pygmaeus*) was neglected and the few studies that existed were usually conducted in zoos and on very small samples. Our research in Borneo has shown thatthe little we know of orang-utans was at times distorted by the study environment of the zoo and by the attitudes about orang-utans. In the first part of our talk we refer to the nature of prejudice that prevented insight into this species and generally provide an overview of orang-utan behaviour in the natural habitat, incorporating the latest knowledge of fieldwork including our own work. The second part of our talk will report our results on the first major study of handedness in orangutans. Handedness reflects a characteristic of brain-function once thought to be unique to humans. It is now known that lower primates are predominantly left handed and that the evolution of a bipedal posture in higher primates coincided with a shift to right handedness. Orang-utans represent an exception to this pattern of hominoid evolution, being both apes and retaining an arboreal existence. Study of their hand preference therefore provides insight into the evolution of brain lateralisation".

Wednesday, 20th March 1996: Associate Professor G.A. Woolsey, Dept. of Physics, University of New England, NSW delivered an address on "Lightning -Nature's Sound and Light Show". The following is an abstract of the talk supplied by the speaker:-"At any moment, there are about 2000 thunderstorms taking place around

the globe. They have their origins in thunderclouds, each of which is a turbulent soup of ice and water particles. Collisions between the particles cause electrons to transfer from one particle to another, so that ultimately, the top and bottom of a cloud become oppositely charged. This charge can build up until the electric voltage between a cloud and ground, or between two clouds, exceeds hundreds of millions of volts. This leads to the generation of a large current of electricity flowing in a narrow channel through the atmosphere for a fraction of a second. The flow of current causes the lightning flash, and heats the air along its path to a temperature of over 20 000 degrees. This sudden temperature increase raises the air pressure in the lightning channel to such a level that a shock wave is produced, and hence thunder is generated. The talk examined the processes of charge transfer in clouds, the nature of the lightning flash, and the acoustics of thunder; and will be illustrated with practical demonstrations. Advice will be given on how to stay safe in a thunderstorm, so that you can relax and enjoy the excitement of Nature's most spectacular light and sound show".

Members and visitors attended both meetings in the Main (Somerville) Lecture Theatre, Department of Physics, University of New England, Armidale NSW.

SOUTHERN HIGHLAND BRANCH REPORT FOR 1995/96

The Branch held seven meetings as follows:- April 13th 1995, Professor Neville Fletcher of the Australian National University in Canberra addressed 30 members and visitors on "The Acoustics of Musical Instruments" at the Chevalier College Music Centre. The meeting was joint with the Berrima District Music Group. Professor Fletcher combined with Megan Corlette, Christine Tilley and Dal Oldham in performing Teleman's E Minor Quartet for flute, violin, continuo and cello. Mr. Ian Cooper of the Frensham School proposed a vote of thanks.

Thursday 25th May 1995, Dr. Graeme I. Pearman, Meteorologist, Div. of Atmospheric Physics, C.S.I.R.O. Aspendale Vic, spoke on "The Impact on Australia of Global Warming". The meeting took place at the Moss Vale College of TAFE, N.S.W. 29 members and visitors attended. Mrs. Jan Grose proposed a Vote of thanks. Thursday 6th July 1995, Dr. F.L. Sutherland of the Australian Museum, Sydney NSW, addressed 36 members and visitors on "The Demise of the Dinosaurs". The meeting took place at Frensham School. Miss Shirley Walton offered a vote of thanks.

Thursday 7th September, 1995 A meeting, held at Craigieburn NSW, was addressed by Dr. Peter Krug of the Optical Fibre Technology Centre, University of Sydney, on "Optical Fibre Technology and the Future". 35 members and visitors were present. A vote of thanks was proposed by Mr. George Thirkell.

Thursday 19th October, 1995, Professor Keith L. Williams of the School of Biological Sciences, Macquarie University, North Ryde, NSW, addressed 40 members and visitors on "The Human Genome" at "Links House" Hotel Bowral. The vote of thanks was moved by Mr. Dick Flatt.

Sunday 19th November, 1995, Mr. Marsden Hordern, naval historian of Warrawee, Sydney NSW delivered an address on "Australia's Debt to Captain Stokes and the "Beagle" at Frensham School. 24 Members and visitors attended. A vote of thanks was proposed by Mr. Roy Perry.

The Southern Highlands Branch of the Society received donations for the purpose of restoration of Dr. Henry Gratton Douglass's grave as follows:- $200 from Douglass Baglin, $200 from Barbara King, $100 from the Royal Society of NSW and $1500 from the Chancellor's Fund of the University of Sydney. Dr. H.G. Douglass represents a link with the early forerunners of the Royal Society of NSW reaching back to the 1821 Philosophical Society of Australasia.

ABSTRACT OF PROCEEDINGS

April 5th, 1995

The 1048th General Monthly Meeting was held at the Australian Museum. The President, Mr. J.R. Hardie, was in the Chair and 30 members and visitors were present. The 128th Annual General Meeting. Same location. The President, Mr. J.R. Hardie was in the Chair, and 30 members and visitors attended. The Annual Report of Council for 1994-1995 and the Financial Report for 1994 were adopted, Messrs Wylie and Puttock were elected Auditors for 1995.

The following AWARDS for 1994 were announced:

James Cook Medal:-Sir Gustav Nossal Kt, CBE, AC (not present).

Clarke Medal (Botany) Joint Award:-Dr. Barbara Gillian Briggs and Prof. C.A. Atkins (not present).

Edgeworth David Medal:- Richard Hume Middleton.

Royal Society of New South Wales Medal:- Dr. Edmund Clarence Potter.

Archibald Olle Prize:- Mr. Michael Organ.

These Awards were presented by the President to the attending medallists.

Special arrangements were made for Prof. C.A. Atkins and for Sir Gustav Nossal.

The Walter Burfitt Prize was not awarded for 1994.

The following Office-Bearers and Council Members for 1995/1996 were elected:

President:	Dr. D.F. Branagan
Vice-Presidents:	Mr. J.R. Hardie
	Prof. J.H. Loxton
	Dr. E.C. Potter,
	Dr. F.L. Sutherland
	Dr. D.J. Swaine
Honorary Secretaries:	
General:	Mr. G.W.K. Ford MBE
Editorial:	M. Krysko von Tryst
Honorary Treasurer:	A/Prof. D.E. Winch
Honorary Librarian:	Miss P.M. Callaghan
Members of Council:	Dr. R.S. Bhathal
	Dr. R.R. Coenraads
	Dr. A.A. Day
	Dr. G.C. Lowenthal
	Dr. D.J. O'Connor
	Prof. W.E. Smith
	Prof. W. VaggNew
England Branch Representative:	Prof. S.C. Haydon
Southern Highlands Branch Representative:	Dr. K.L. Grose.

The retiring President, Mr. J.R. Hardie, who had chaired both meetings to this point, yielded the Chair to the incoming President, Dr. D.F. Branagan. Mr. J.R. Hardie presented his Presidential Address "Designs on Learning". A vote of thanks was proposed by Dr. G.C. Lowenthal.

May 3rd, 1995 The 1049th General Monthly Meeting was held in the Australian Museum, Sydney. The Vice President, Dr. F.L. Sutherland was in the Chair and 13 members and visitors were present. Mr. Ross Pearson (formerly ABC) addressed the audience on "Ross Smith - Soldier, Patriot and Pioneer Airman", a biographical account of Ross Smith's flight achievements during and after the war. The talk was of great interest and many questions were raised. A vote of thanks was proposed by Mr. G.W.K. Ford, MBE.

June 7th, 1995 The 1050th General Monthly Meeting was held at the Australian Museum, Sydney. The meeting was opened and chaired by the Vice-President, Mr. J.R. Hardie. 26 members and visitors were present. A/Prof. Denis Winch introduced Prof. K. Runcorn FRS, to address the meeting on "The Origins of the Solar System". A/Prof. Winch proposed the vote of thanks.

July 5th, 1995 The 1051st General Monthly Meeting took place in the Australian Museum, Sydney. The Vice-President, Dr. F.L. Sutherland opened and chaired the meeting 19 members and

visitors attended. Dr. Mary White (Consultant Palaeobotanist) gave an address entitled "After the Greening - The Browning of Australia". Mr. John Grover OBE proposed a vote of thanks.

August 2nd, 1995 The 1052nd General Monthly Meeting took place at the Australian Museum, Sydney. The President Dr. D.F. Branagan was in the Chair and 24 members and visitors were present. Dr. Edmund Potter delivered an address entitled "Learning new lessons from the 1994 Bushfires or Seeing the Wood for Trees". The address was illustrated with many slides, photographs and diagrams of extreme interest. Dr. Paul Adams of ANZAAS proposed a vote of thanks.

September 13th, 1995 The 1053rd General Monthly Meeting was held at the Australian Museum. The President Dr. D.F. Branagan was in the Chair and 22 visitors and members attended. Sir Gustav Nossal, AC Kt CBE, was introduced and presented with the James Cook Medal for 1994. Sir Gustav then addressed the meeting on "Medical Science and Human Goals: A struggling Pilgrim's Progress". The vote of thanks was offered by Dr. Norbert Kelvin.

October 4th, 1995 The 1054th General Monthly Meeting was held at the University of Western Sydney. The Vice-President Dr. F.L. Sutherland was in the Chair and 27 members and visitors were present. Council noted that one of its Vice-Presidents, Prof. John Loxton was appointed as Deputy Vice-Chancellor (Academic) of Macquarie University, Sydney. Dr. Frank Stootmen, Sen. Lecturer in Physics, University of Western Sydney, delivered an address "Physics and Metaphysics". Dr. Donald Neely proposed the vote of thanks.

November 1st, 1995 The 1055th General Monthly Meeting was held at the Australian Museum. The President Dr. D.F. Branagan was in the Chair and 26 members and visitors attended. Dr. Robert R. Coenraads gave an address entitled "Mexico: Understanding its Culture: Indian or Spanish, a Mestizo Dilemma". Dr. D.J. O'Connor proposed the vote of thanks.

THE ROYAL SOCIETY OF NEW SOUTH WALES

AUDITORS REPORT TO THE MEMBERS

Scope

We have audited the financial statements, being the balance sheet, accumulated funds account, statement of cash flows and notes to and forming part of the financial statements of The Royal Society of New South Wales for the year ended 31 December 1995. The society's officers are responsible for the preparation and presentation of the financial statements and the information they contain. We have conducted an independent audit of these financial statements in order to express an opinion on them to the members of the society.

Our audit has been conducted in accordance with Australian Auditing Standards to provide reasonable assurance as to whether the financial statements are free of material misstatement. Our procedures included examination, on a test basis, of evidence supporting the amounts and other disclosures in the financial statements, and the evaluation of accounting policies and significant accounting estimates. These procedures have been undertaken to form an opinion as to whether, in all material respects, the financial statements are presented fairly in accordance with Australian accounting standards so as to present a view of the society which is consistent with our understanding of its financial position and the results of its operations and cash flows.

The audit opinion expressed in this report has been formed on the above basis.

Audit Opinion

In our opinion the financial statements of The Royal Society of New South Wales are properly drawn up:

(a) so as to give a true and fair view of the state of affairs of the society at 31 December 1995 and of the results and cash flows of the society for the year ended on that date; and

(b) in accordance with applicable Accounting Standards.

WYLIE & PUTTOCK
Chartered Accountants
ALAN M PUTTOCK

189 Kent Street
SYDNEY NSW 2000

THE ROYAL SOCIETY OF NEW SOUTH WALES

BALANCE SHEET AT 31 DECEMBER 1995

1994		NOTE	1995
	CURRENT ASSETS		
3685	Cash	2	4008
3945	Receivables	3	6002
18157	Investments	5	4883
0	Inventories		0
1505	Other	4	280
27292	TOTAL CURRENT ASSETS		15173
	NON-CURRENT ASSETS		
0	Receivables		0
120989	Investments	5	128872
0	Inventories		0
17225	Property, plant and equipment	6	17145
0	Intangibles		0
0	Other		0
138214	TOTAL NON-CURRENT ASSETS		146017
165506	TOTAL ASSETS		161190
	CURRENT LIABILITIES		
3392	Creditors and borrowings	7	411
0	Provisions		0
1954	Other	8	2258
5346	TOTAL CURRENT LIABILITIES		2669
	NON-CURRENT LIABILITIES		
0	Creditors and borrowings		0
0	Provisions		0
86	Other	8	71
86	TOTAL NON-CURRENT LIABILITIES		71
5432	TOTAL LIABILITIES		2740
160074	NET ASSETS		158450

D.F. Branagan *President* D.J. O'Connor *Hon Treasurer*

THE ROYAL SOCIETY OF NEW SOUTH WALES

BALANCE SHEET AT 31 DECEMBER 1995 - (Cont.)

1994		NOTE	1995
	EQUITY		
7311	Library reserve	9	7311
9928	Library fund	10	10170
21973	Trust funds	11	21535
120862	Other accumulated funds		119434
160074	TOTAL EQUITY		158450
	Capital and leasing commitments	16	
	Contingent liabilities	17	

D F BRANAGAN President   D J O'CONNOR Honorary Treasurer

ACCUMULATED FUNDS ACCOUNT
For the year ended 31 December 1995

1994		NOTE	1995
(6908)	Operating surplus (deficit)		(2014)
434	Donations and interest to library fund	10	828
(6474)			(1186)
127770	Accumulated funds at the beginning of the financial year		120862
0	Transferred from library fund	10	586
121296			120262
434	Transferred to library fund	10	828
120862	Accumulated funds at end of the financial year		119434

The accompanying notes form part of these financial statements

THE ROYAL SOCIETY OF NEW SOUTH WALES

STATEMENT OF CASH FLOWS
For the year ended 31 December 1995

1994		NOTE	1995
	CASH FLOWS FROM OPERATING ACTIVITIES		
8485	Members subscriptions and donations		11280
17195	Other revenue sources		11171
4725	Interest received		7437
(39513)	Administration and other operating expenses		(34357)
(9108)	Net cash provided by (used in) operating activities	18	(4469)
	CASH FLOWS FROM INVESTING ACTIVITIES		
7339	Net reduction in investments		5391
0	Purchase of office equipment		(599)
7339	Net cash provided by investing activities		4792
(1769)	NET INCREASE (DECREASE) IN CASH HELD		323
5454	Cash at the beginning of the financial year		3685
3685	CASH AT THE END OF THE FINANCIAL YEAR		4008

The accompanying notes form part of this statement of cash flows

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1995

1 STATEMENT OF ACCOUNTING POLICIES

The accounts have been prepared in accordance with applicable Accounting Standards. The accounts have also been prepared on the basis of historical costs and do not take into account changing money values or, except where stated, current valuations of non-current assets. Cost is based on the fair values of the consideration given in exchange for assets. The accounting policies have been consistently applied, unless otherwise stated.

The following is a summary of the significant accounting policies adopted by the society in the preparation of the accounts.

(a) Non-Current Investments

Investments are brought to account at cost. The carrying amount of investments is reviewed annually to ensure it is not in excess of the recoverable amount of the investments.

(b) Property, Plant & Equipment

Property, plant and equipment are brought to account at cost or at independent valuation, less, where applicable, any accumulated depreciation or amortisation. The carrying amount of property, plant and equipment is reviewed annually to ensure it is not in excess of the recoverable amount from these assets.

The depreciable amount of all fixed assets is depreciated over their useful lives commencing from the time the asset is held ready for use.

The exception to the above policy is the society's library which is brought to account at its 1936 independent valuation, a more recent valuation not being available.

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1995

1 STATEMENT OF ACCOUNTING POLICIES - (Cont.)

(c) Unearned Revenue

The unearned revenue shown in the accounts will be brought to account in the next financial year.

(d) Comparative Figures

Where required by Accounting Standards comparative figures have been adjusted to conform with changes in presentation for the current financial year.

1994		1995
	2 CASH	
	Included in cash are:	
0	Cash on hand	68
3685	Cash at bank	3940
3685		4008
	3 RECEIVABLES	
	Included in Current Receivables are:	
3408	Debtors for subscriptions	1645
3408	Less provision for doubtful debts	1645
0		0
1731	Debtors for contributions towards printing Journal and Proceedings	2662
2214	Other debtors	3340
3945		6002

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1995

1994		1995
	4 OTHER ASSETS	
	Included in Current Other Assets are:	
1505	Prepayments	280
	5 INVESTMENTS	
	Included in Current Investments are:	
18157	Deposits at call	4883
	Included in Non-Current Investments are:	
120989	Interest bearing deposits	128872
	6 PROPERTY PLANT AND EQUIPMENT	
	Included in Property, Plant & Equipment are:	
603	Office equipment and furniture - at cost less depreciation	1125
3012	Office equipment - at 1991 valuation less depreciation	2410
13600	Library - at 1936 valuation	13600
10	Pictures - at cost less depreciation	10
17225		17145
	7 CREDITORS AND BORROWINGS	
	Included in Current Creditors & Borrowings are:	
152	Sundry creditors and accruals	411
3240	Unearned revenue	0
3392		411

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1995

1994		1995
	8 OTHER LIABILITIES	
	Included in Current Other Liabilities are:	
16	Life members subscriptions prepaid	16
286	Membership subscriptions paid in advance	414
1652	Journal and Proceedings subscriptions paid in advance	1828
1954		2358
	Included in Non-Current Other Liabilities are:	
87	Life members subscriptions prepaid	71
	9 LIBRARY RESERVE	
7311	Balance at 1 January	7311
0	Movement for year	0
7311	Balance at 31 December	7311
	10 LIBRARY FUND	
9494	Balance at 1 January	9928
434	Donations and interest	434
9928		10756
0	Library purchases and expenses	586
0	Contribution towards printing Journal and Proceedings	0
0		586
9928	Balance at 31 December	10170

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1995

1994		1995
	11 TRUST FUNDS	
	Included in Trust Funds are:	
3585	Clarke Memorial Fund	3534
6657	Walter Burfitt Prize Fund	6854
3954	Liversidge Bequest Fund	3620
7777	Olle Bequest Fund	7527
21973		21535
	12 CLARKE MEMORIAL FUND	
5000	Capital	5000
	Revenue	
238	Income for year	351
570	Expenditure for year	402
(332)	Surplus (deficit) for year	(51)
(1083)	Balance at 1 January	(1415)
(1415)	Balance at 31 December	(1466)
3585	Total fund capital and revenue	3534
	13 WALTER BURFITT PRIZE FUND	
3000	Capital	3000
	Revenue	
143	Income for year	211
0	Expenditure for year	14
143	Surplus (deficit) for year	197
3514	Balance at 1 January	3657
3657	Balance at 31 December	3854
6657	Total fund capital and revenue	6854

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1995

1994		1995
	14 LIVERSIDGE BEQUEST FUND	
3000	Capital	3000
	Revenue	
143	Income for year	210
26	Expenditure for year	544
117	Surplus (deficit) for year	(334)
837	Balance at 1 January	954
954	Balance at 31 December	620
3954	Total fund capital and revenue	3620
	15 OLLE BEQUEST FUND	
4000	Capital	4000
	Revenue	
191	Income for year	281
0	Expenditure for year	531
191	Surplus (deficit) for year	(250)
3586	Balance at 1 January	3777
3777	Balance at 31 December	3527
7777	Total fund capital and revenue	7527
	16 CAPITAL AND LEASING COMMITMENTS	
0	Capital and leasing expenditure commitments contracted for but <u>not</u> already included in the balance sheet	0

THE ROYAL SOCIETY OF NEW SOUTH WALES

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1995

1994		1995
	17 CONTINGENT LIABILITIES	
	NIL	
	18 CASH FLOW INFORMATION	
	Reconciliation of net cash provided by operating activities to operating surplus (deficit)	
(6908)	Operating surplus (deficit)	(2014)
434	Library fund donations & interest	828
	Non-cash flows in operating surplus	
824	Depreciation	679
	Changes in assets and liabilities	
148	Reduction (increase) in receivables	(2057)
(26)	Reduction (increase) in prepayments	1225
(2290)	Increase (reduction) in unearned revenue	(3240)
(6505)	Increase (reduction) in creditors	259
(14)	Increase (reduction) in members subscriptions in advance	113
530	Increase (reduction) in journal subscriptions in advance	176
119	Increase (reduction) in trust funds	(438)
9108	Net cash provided by (used in) operating activities	(4469)

THE ROYAL SOCIETY OF NEW SOUTH WALES

DETAILED INCOME AND EXPENDITURE ACCOUNT
For the year ended 31 December 1995

1994		1995
	INCOME	
9897	Membership subscriptions	11245
306	Application fees	233
10203		11478
6154	Subscriptions and contributions to journal publication costs	9188
16357	Total membership and journal income	20666
6100	Interest received	8563
551	Sale of reprints	470
2403	Sale of back numbers	1096
213	Sale of other publications	55
26	Donations - general	6
0	Summer school surplus	836
0	Geological excursion surplus	163
60	Annual dinner surplus	0
101	Other income	288
25811		32143
	Less EXPENSES	
2500	Accountancy fees	2630
0	Annual dinner deficit	105
1300	Audit fees	1370
82	Bank charges & government duties	97
200	Branches of the society	300
824	Depreciation	679
538	Entertainment expenses	316
618	Insurance	836
10782	Journal publication & distribution costs	12507
0	Library expenses	586
850	Miscellaneous expenses	120
314	Monthly meeting expenses	474
2129	Newsletter printing & distribution	2464
655	Postage	516
865	Printing & stationery	888
1732	Provision for doubtful debts	77
2000	Rent	2000
78	Repairs	0

THE ROYAL SOCIETY OF NEW SOUTH WALES

DETAILED INCOME AND EXPENDITURE ACCOUNT - (Cont)
For the year ended 31 December 1995

1994		1995
5603	Salaries	6828
1312	Summer school deficit	216
0	Superannuation contributions	738
337	Telephone	410
32719		34157
(6908)	DEFICIT for the year	(2014)

END OF FINANCIAL STATEMENTS

AWARDS

THE WALTER BURFITT PRIZE

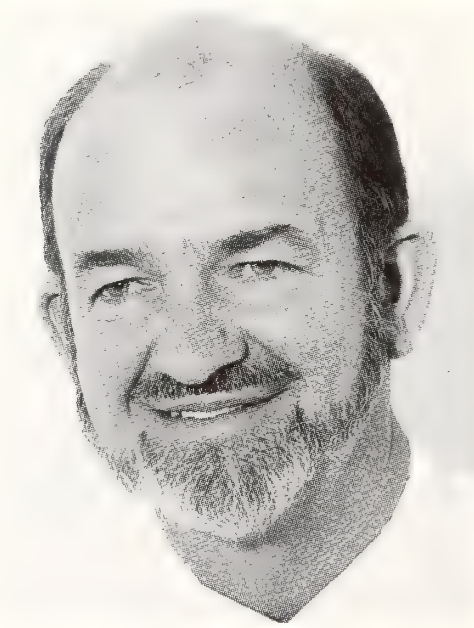
Richard M. Manchester

The Walter Burfitt Prize for 1995 is awarded to Richard M. Manchester, PhD, FAA, Chief Scientist at the CSIRO Australian Telescope National Facility. He is clearly one of the foremost scientists in the field of radio pulsars, and leads an international group which is pre-eminent in the discovery and interpretation of pulsars. Amongst his recent achievements are the Parkes Southern pulsar survey, the discovery of a bright pulsar which is also an x-ray source, the optical identification of the white dwarf companion of this pulsar which led to its age determination, and the study of supernova remnants. His group has discovered a large number of pulsars and their work is certainly astrophysically very important in areas of fundamental physics and in areas relevant to the establishment of a long-term standard of terrestrial time.

Tributes from eminent colleagues in Australia and overseas attest to Dr. Manchester's inspiration to his research group, to his outstanding qualities as a team leader, to his successful co-authorship (with a Nobel Laureate) of the definitive textbook on pulsars and to his key role in keeping Australia at the forefront of pulsar research.

There is no doubt that Dr. Manchester's research during the past six years is of the highest merit, thereby fulfilling the conditions of the Award. He is widely recognised in the world as one of the top three in his field. It is fitting that the Royal Society of New South Wales endorses Dr. Manchester's excellent scientific work by the award of the Walter Burfitt Prize. [D.J. Swaine]

CLARKE MEDAL



Christopher McAulay Powell

In 1995 this medal is awarded for contributions in the field of Geology.

Professor Powell is a graduate of the Universities of Queensland and Tasmania. After a post-doctoral fellowship in the USA he took up a position at Macquarie University in 1970, where he remained on the teaching staff until 1989. In 1990 he was appointed Professor of Geology at the University of Western Australia.

His research began in Tasmania, where he studied polyphase deformation of the Late Proterozoic and Palaeozoic rocks, but it soon took him into the Himalayas for similar studies.

While at Macquarie University he devoted a considerable time to structural studies of the

Lachlan Foldbelt, publishing controversial papers on "kinking" and palaeogeography, much of which was later incorporated as a long chapter in *Phanerozoic Earth History of Australia* (edited J.J. Veevers, 1984).

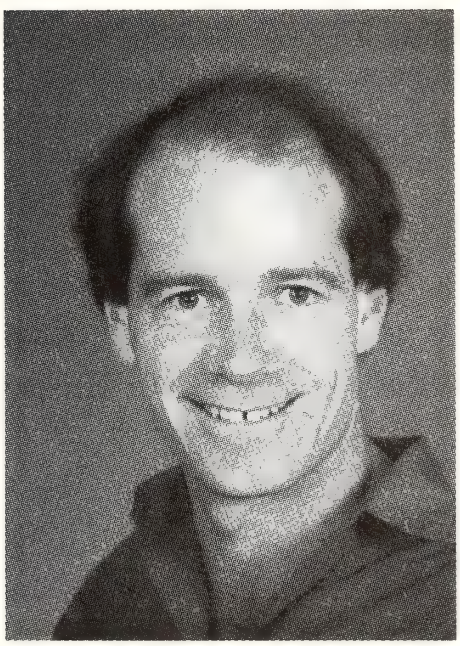
In the Himalayas Professor Powell also became concerned with aspects of plate tectonics, work which led to his revolutionary paper on collision tectonics *Continental underplating model for the rise of the Tibetan Plateau* (1986). This was followed by a series of papers, with colleagues, on the sea-floor spreading pattern of the Indian Ocean.

Recent work has dealt with the concept of *Rodinia* - the Precambrian supercontinent, which has involved palaeomagnetic and tectonic studies in Western Australia, and collaborative studies with numerous overseas colleagues.

Professor Powell's enthusiasm and sustained critical research has stimulated numerous students who have taken up his ideas in a wide range of topics related to many of the major large-scale unsolved problems of the Earth.

Professor Powell can be rightly said to have "so distinguished himself by original research" to be worthy of the award of the Clarke Medal for 1995.

THE EDGEWORTH DAVID MEDAL FOR 1995



Anthony Bruce Murphy

Anthony Murphy has made significant contributions to the advancement of Australian science and in particular to the understanding of aspects of plasma physics. He graduated from the University of Sydney with a PhD in 1986 with an outstanding academic record. During his postgraduate studies he performed definitive measurements of the propagation of Al´ven waves in fusion plasmas. Al´ven waves can be used to heat these plasmas to the temperatures required for fusion reactions. He left Australia for three years to work at the Max-Planck -Institut for Plasmaphysics in Germany and continued his work on the heating of plasmas for application in fusion. On his return to Australia in 1989 he joined CSIRO and was recently promoted to the position of Principal Research Scientist in the division of Applied Physics. He is only the second scientist in the Division's history to be promoted to this level by the age of 35.

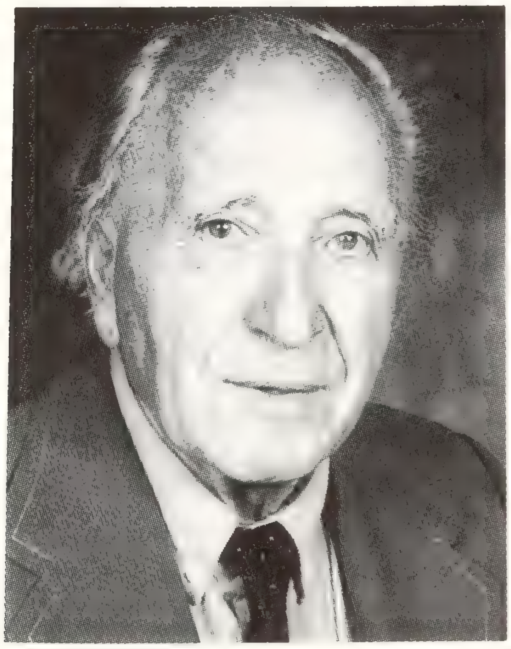
Anthony Murphy has made significant advances in the theory of transport phenomena in plasma gases by developing a combined fusion coefficient formulation which simplifies the treatment of high-temperature gas mixtures. This work was presented to the Twelfth International Symposium on Plasma chemistry in Minneapolis. He has derived the most reliable set available of transport properties of the main industrial plasma gases, with 50% improvements in the accuracy of calculations of parameters such as the thermal conductivity of gas mixtures. He has developed plasma diagnostic techniques using laser-scattering methods to measure, for the first time, the full range of temperatures present in thermal plasmas.

His work has major applications in waste destruction, using thermal plasmas to destroy noxious chemicals, in welding and in plasma synthesis. An agreement has been signed with the Commonwealth Government to construct a plant to destroy Australia's stockpile of ozone-depleting substances. The model he has developed will be used to optimise the reactor geometry and other

process parameters to ensure destruction while avoiding recombination reactions which produce other undesirable products.

Anthony Murphy is a young scientist who has built up an impressive track record in theoretical and experimental research on the science and application of gas plasmas. He is a worthy recipient of the Edgeworth David Medal.

THE SOCIETY'S MEDAL



Gerhart C. Lowenthal

Dr. Gerhart Lowenthal graduated from the University of Melbourne with the degrees of BA, BSc and the Diploma of Public Administration. His doctorate is from the University of New South Wales, and he is a Fellow of the Australian Institute of Physics. He is an Honorary Member of the Australian and New Zealand Nuclear Medicine Society which has instituted an annual lecture entitled the Lowenthal Lecture.

After working as a physicist at the Department of Supply, Dr. Lowenthal moved to the CSIRO National Standards Laboratory, where he carried out research on the International Temperature Scale at liquid hydrogen temperatures. After being appointed to the Australian Atomic Energy Commission, he set up Australian Standards of Radioactivity which were recognised internationally. Dr. Lowenthal was also collaborating with International Committee for Weights and Measures in Paris. This and other work in connection with scientific co-operation with France culminated with the prestigious award of Chevalier del' Ordre National du Mérite. Dr. Lowenthal's research, carried out in Australia and overseas, was primarily in various aspects of radioactivity and nuclear science, especially in the important matter of setting up standards. This work is recognised internationally and is the basis of Australia being represented on the Consultative Committee for Ionising Radiations of the International Committee for Weights and Measures in Paris.

Dr. Lowenthal has been and still is an active member of the Royal Society of New South Wales as a member of Council and as a co-convener of Summer Schools in Medicine. He has been the prime mover in arranging several successful joint seminars with other scientific societies, the most recent one being to mark the centenary of Röntgen's discovery of X-rays.

He has been on the editorial board of scientific journals and is active in retirement as an Honorary Visiting Fellow in the School of Mechanical and Manufacturing Engineering at the University of New South Wales, and as a consultant to the Department of Nuclear Medicine, Royal Prince Alfred Hospital.

In view of his noteworthy contributions to science, especially in the fields of radioactivity and nuclear science, and of his past and continuing activities in the Royal Society of New South Wales, it is surely fitting that Dr. Gerhart Lowenthal should receive the Society's Medal.

ANNUAL DINNER ADDRESS

Royal Society of New South Wales, Wednesday, 13 March 1996

Emeritus Professor Richard Limon Stanton, AO

Mr. President, Ladies and Gentlemen

Thank you for having me as your guest and for asking me to speak to you on this pleasant occasion.

When, a week or so ago, I began to think what I might say this evening, I was reminded of a little tale I heard in Cambridge when I was there some time ago. The story goes that a famous English physicist was attending a late afternoon scientific meeting in London. The meeting, which he had thought would be quite short, turned out to be rather long, but eventually, though somewhat agitatedly, he managed to extricate himself, and he hurried out onto the street where he hailed a cab for the railway station. As they arrived at the station he looked across and was relieved to see that the Bristol train - it was the Bristol express, non-stop to Bristol - was still at the platform. He quickly paid off the cabbie, rushed over to the counter to buy his ticket, and then half ran to the train, which he boarded just as the whistle blew. As he walked along the centre aisle of the carriage, and as the train gathered speed through the inner suburbs of London, he noticed that there was a window seat still vacant. He was pleased about that; it was a lovely, mellow early summer's evening, and he thought how much he would enjoy the scenery as they travelled along.

However, just as he was settling comfortably and contentedly into his seat, he suddenly remembered that he had left his position at the University of Bristol some two and a half years previously, and that he was now head of the Department of Physics at Cambridge. Then he recollected that he had driven up to London by motor car. And finally he recalled that he had brought his wife with him!

I have often thought that sort of happy state of semi-oblivion was one of the great rewards of a life devoted to Science - but I tell the story not just as one more tale of an absent-minded old scientist lost in his thoughts, but to introduce one of my present concerns about science; that as scientific activity becomes more and more public, many of our policy-makers may be losing sight of the importance of the individual scientist, often working substantially on his own.

I suspect that there is now a widespread view in government and among the general public that science is substantially a matter of teams - of what is now referred to as "team research". We read almost every few days of large allocations and grants for medical and various technological investigations to be carried out by major research institutions, of tax-concessions for large-scale industrial research and development projects, of the setting up of new co-operative research centres and so on. I do not wish to denigrate team research, or to deny the necessity of substantial funding for the expensive items of equipment that many sciences require these days, but I do worry that many of those in power may sometimes lose sight of the fact that scientists, like other creative intellects, are highly individualistic, and that it is the ingenious, highly perceptive, gently-obsessed individual who is the ultimate vital element in the advancement of science. I do not, of course, know whether the invention of the wheel came from individual or team research, but we all know that most of the world's momentous advances in scientific understanding have come from individual minds. We may think of the years 1664-65 when, with Cambridge closed because of the Great Plague, Newton spent much of his time walking and meditating in the Lincolnshire countryside: in those two years of relative solitude and quiet contemplation he invented the calculus, discovered the law of universal gravitation, and recognised that white light is composed of light of all the colours. Or we may think of Fermat, the great early number theorist and perhaps the first perceiver of the calculus, in everyday life a French magistrate, quietly and enjoyably pondering patterns of numbers as he walked home in the evening after a day presiding over his court; or of Darwin, busily collecting in the South American jungle, his mind full of the idea that organisms evolved and that

such evolution might be driven by natural selection. And so it goes on: Copernicus, Galileo, Leibniz, Linnaeus, Pasteur, Rutherford, Einstein, Curie, Goldschmidt, Pauling and others - all great individuals. Of course most scientists - all apart from the most basic originators - are involved in a sort of serial team research in so far as each small contribution adds to those that have been made earlier. As Newton said " If I have seen a little farther than others, it is because I have stood on the shoulders of giants". All of us have hoisted ourselves onto the shoulders of our own particular giants, but this is clearly not what I mean when I refer to present-day large-scale team activity, which all too many bureaucrats and administrators seem to see as constituting the major element of modern scientific research.

Tied closely to this is what also seems to be the widely held view in government and other circles that increasing scientific productivity involves little more in principle than the allocation of greater amounts of money and employment of more scientists: if there are more gas meters to be read one employs more gas meter readers. On the contrary scientists are artists: as deeply intellectual beings they vary in their abilities and styles in the same way as do writers, painters, composers and other creative individuals. Indeed almost forty years ago Sir Eric Ashby, a former Professor of Botany at the University of Sydney, maintained that Science was as much a cultural achievement as any other of mankind - as great as any in the arts. It was in the same vein that the great mathematician Poincaré remarked " a scientist worthy of the name, above all a mathematician, experiences in his work the same impression as an artist; his pleasure is as great, as of the same nature". As in great art there is, too, no place for egalitarianism in great science; it is from the unusually perceptive individual that the vital first insight comes, and I think that this should never be lost sight of by those who organise modern science.

The importance of the individual intellect remains, of course, well-recognised by the scientific community itself, and I am sure could never be lost sight of by those who really know how science works. I know of no more wonderful story of appreciation of one scientist by another than that of William Lilly written about the year 1640 - a story probably well-known to the mathematicians present this evening. Lilly records an amusing - and almost incredible - account of the meeting between Lord Napier of Merchiston, the inventor of logarithms, and henry Briggs of Gresham College, London, who computed the first table of common logarithms.

"One John Marr", Lilly recounts, "an excellent mathematician and geometrician", had gone "into Scotland before Mr. Briggs, purposely to be there when these two so learned persons should meet. Mr. Briggs appoints a certain day when to meet in Edinburgh; but failing thereof, the lord Napier was doubtful he would not come. It happened one day as John Marr and the lord Napier were speaking of Mr. Briggs: Ah, John (said Napier), Mr. Briggs will not now come.' At the very moment one knocks at the gate; John Marr hastens down, and it proved Mr. Briggs to his great contentment. He brings Mr. Briggs up into my lord's chamber, where almost *one quarter of an hour* was spent, each beholding each other with admiration, *before one word was spoke*." there are all sorts of ways of recognising individual talent and I suppose speechless admiration is one of them.

Team research and vast funding are now with us and are here to stay, and they are of course essential for the huge technical investigations of modern medicine, of extra-terrestrial space, particle physics, marine geophysics, agriculture and so forth, and for many other scientific activities. but I make a plea that in all this we must not forget that great science depends in the end on the remarkable, as I said before, gently-obsessed individual - our old friend on the Bristol train.

And what is it that this individual needs to continue to do good work in the scientific world of today? among his most important needs are time, peace to contemplate, a good library, and the opportunity to talk with fellow scientists of a variety of interests. Much of the stimulus of scientific intercourse comes from talking not only with others of like mind but also from exchanges with those of peripheral or even distant interests.

It is in this latter connection, of course, that many of our more venerable and more general societies play an important part, and in which, I am sure, that our society has an important future.

On that note I should like to thank you again for having me as your guest - and to invite you to join me in a toast to the Society.

NOTICE TO AUTHORS

A "Style Guide" to authors is available from the Honorary Secretary, Royal Society of New South Wales, PO Box 1525, Macquarie Centre, NSW 2113, and intending authors *must* read the guide before preparing their manuscript for review. The more important requirements are summarised below.

GENERAL

Manuscripts should be addressed to the Honorary Secretary (address given above).

Manuscripts submitted by a non-member must be communicated by a member of the Society.

Each manuscript will be scrutinised by the Publications Committee before being sent to an independent referee who will advise the Council of the Society on the acceptability of the paper. In the event of rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere, nor is likely to be published substantially in the same form elsewhere. Well-known work and experimental procedure should be referred to only briefly, and extensive reviews and historical surveys should, as a rule, be avoided. Letters to the Editor and short notes may also be submitted for publication.

Original papers or illustrations published in the Journal and Proceedings of the Society may be reproduced only with the permission of the author and of the Council of the Society; the usual acknowledgements must be made.

PRESENTATION OF INITIAL MANUSCRIPT FOR REVIEW

Typescripts should be submitted on bond A4 paper. A second copy of both text and illustrations is required for office use. Manuscripts, including the abstract, captions for illustrations and tables, acknowledgements and references should be typed in double spacing on one side of the paper only.

Manuscripts should be arranged in the following order: title; names(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgements; appendices; references; names of Institution/Organisation where work carried out/or private address as applicable. A table of contents should also accompany the paper for the guidance of the Editor.

Spelling follows "The Concise Oxford Dictionary".

The Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigaphic names must conform with the International Stratigraphic Guide and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra, ACT 2601, Australia.

Abstract. A brief but fully informative abstract must be provided.

Tables should be adjusted for size to fit the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

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DEVONIAN GEOLOGY OF COPPER MINE RANGE, FAR WEST NEW SOUTH WALES

G. NEEF AND R.S. BOTTRILL

Abstract: The NW-trending Copper Mine Range, 40 km WSW of White Cliffs in far west New South Wales, is bounded in the west by the NW-trending Koonenberry Fault. Fluvial strata forming the range comprise eight ?Emsian-Eifelian (Devonian) units which together are ~3000m thick. They unconformably overlie Precambrian strata, except near Cupala Creek where they unconformably overlie Late Cambrian strata. South of the Copper Mine Range, and adjacent to the eastern margin of the Koonenberry Fault, are brecciated quartzose arenites, which are probably coeval with Unit 2 of Copper Mine Range. Unconformably above them are four units of lightly indurated, fluvial ?late Mid Devonian-Late Devonian strata that are together >1200 m thick. The basal conglomeratic Unit A, >600 m thick, is fault bounded. Unit B, >700 m thick, lies south of Unit A and comprises fine sandstone, which contains a lenticular, 450 m thick sedimentary breccia (Unit C). Unit D is mapped in the north and is younger than Units A, B and C.

Keywords: Mulga Downs Group, sedimentary petrology, fluvial sedimentology, basin analysis, Tabberabberan Orogeny, Kanimblan Orogeny.

INTRODUCTION

The Copper Mine Range, 40 km WSW of White Cliffs in far west New South Wales is a triangular, 24 km long area of 110 km2 with a maximum width of 8 km in the south, and is composed mainly of well exposed Devonian Mulga Downs Group strata (Fig.1). The central, 15 km long part of the range forms a plateau that is 150 m higher in elevation than the Precambrian and Palaeozoic strata which lie adjacent to the range .

The plateau, which is cliffed in the east and has steep slopes towards the plain in the west, is gently tilted to the SE and merges into plains country 8 km SE of Spring Hill. Quartzose sandstones of ?Emsian-Eifelian age underlie the plateau whereas mudstone, shale and a kimberlitic sill, which intrudes the basal Mulga Downs Group 2.5 km south of Spring Hill (Bottrill and Neef, in prep.), form valleys. South of Copper Mine Range the indurated ?Emsian-Eifelian strata form low hills, whereas ?Late Devonian Mulga Downs Group strata form low ground (Fig. 2). This paper is concerned with the stratigraphy, sedimentology, structure and geological history of the Mulga Downs Group both within and south of Copper Mine Range.

PREVIOUS WORK

Kenny's (1934) pioneering studies of the geology of far west NSW were followed by more comprehensive work during the State's 1:250,000 geological mapping project in the 1960s (e.g. Rose et al. 1964; Frenda 1965). Other earlier workers were Warris (1967) and Wilson (1967). There has been little interest in the geology of Copper Mine Range since then.

GEOLOGICAL SETTING

Copper Mine Range lies within the Wonaminta Block and east of the major NNW-trending Koonenberry Fault (Figs 1,2). East of the fault are the Muckabunnya and Hummocks Faults. In a description of the Wonaminta Block, Mills (1992) recognised: Ponto Beds, coeval with the Mid Proterozoic Willyama Supergroup of the Broken Hill Block; Kara Beds, coeval with the Late Precambrian Adelaide System of the Barrier

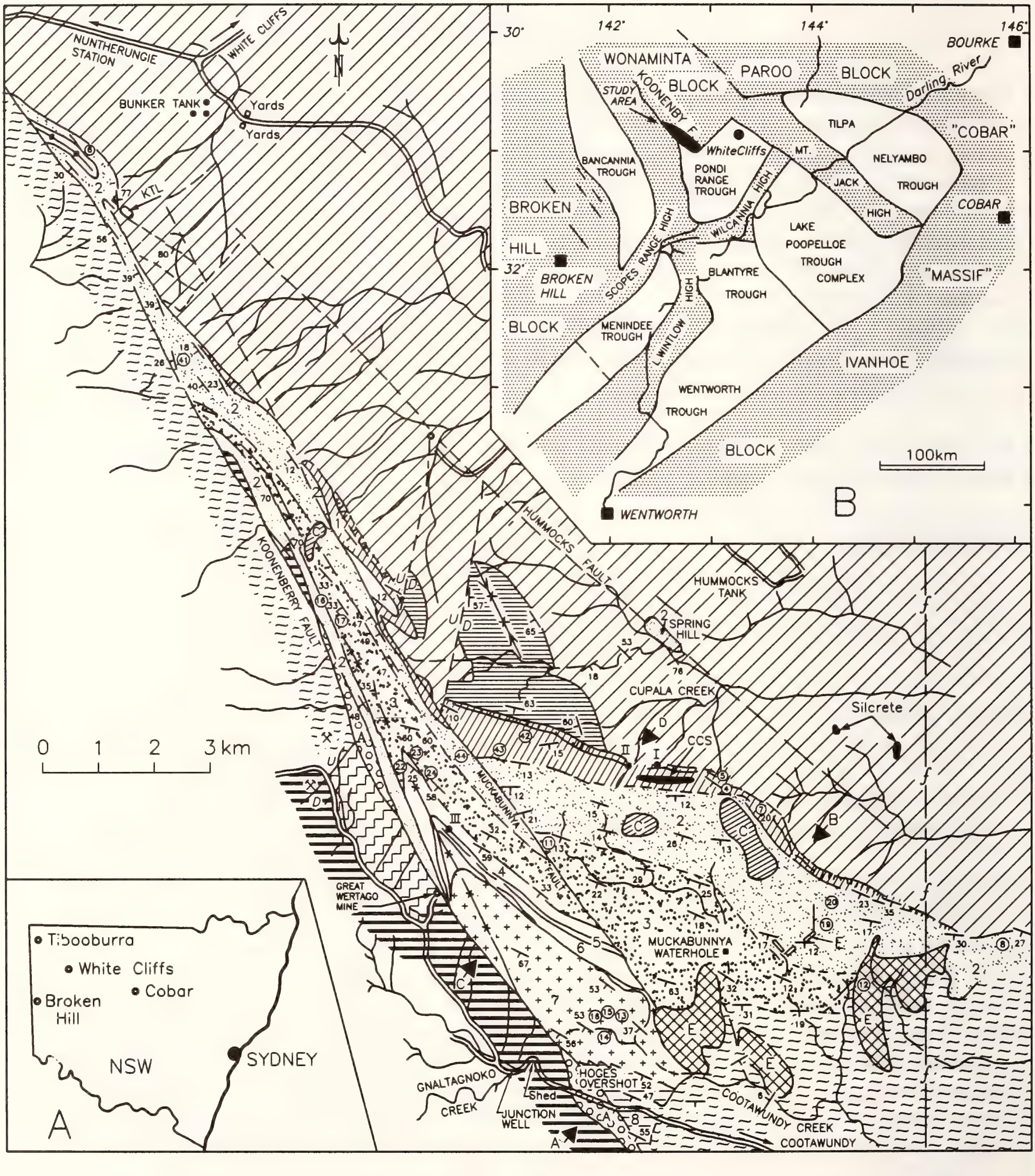
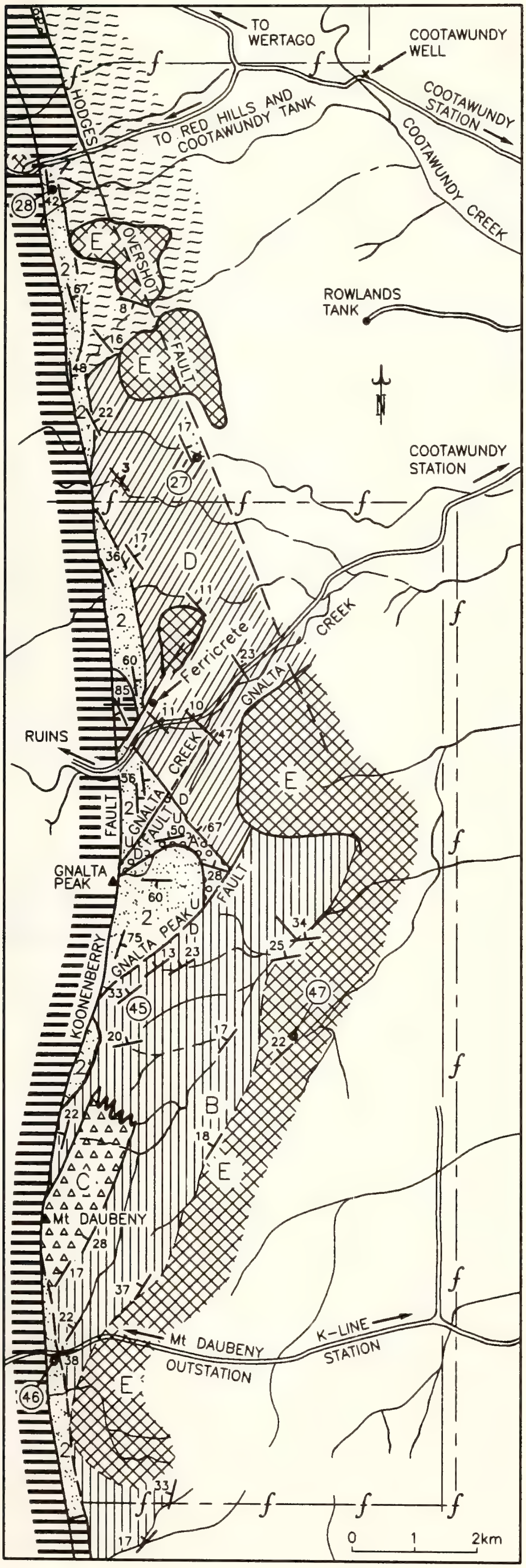


Figure 1. Geology of Copper Mine Range. Inset A shows the location of Broken Hill and Cobar. Inset B shows the location of the study area and elements of the Darling Basin, (horsts stippled) and troughs (after Evans 1977). Key in Figure 2. Note: continuation of the southern end of this map in Figure 2.



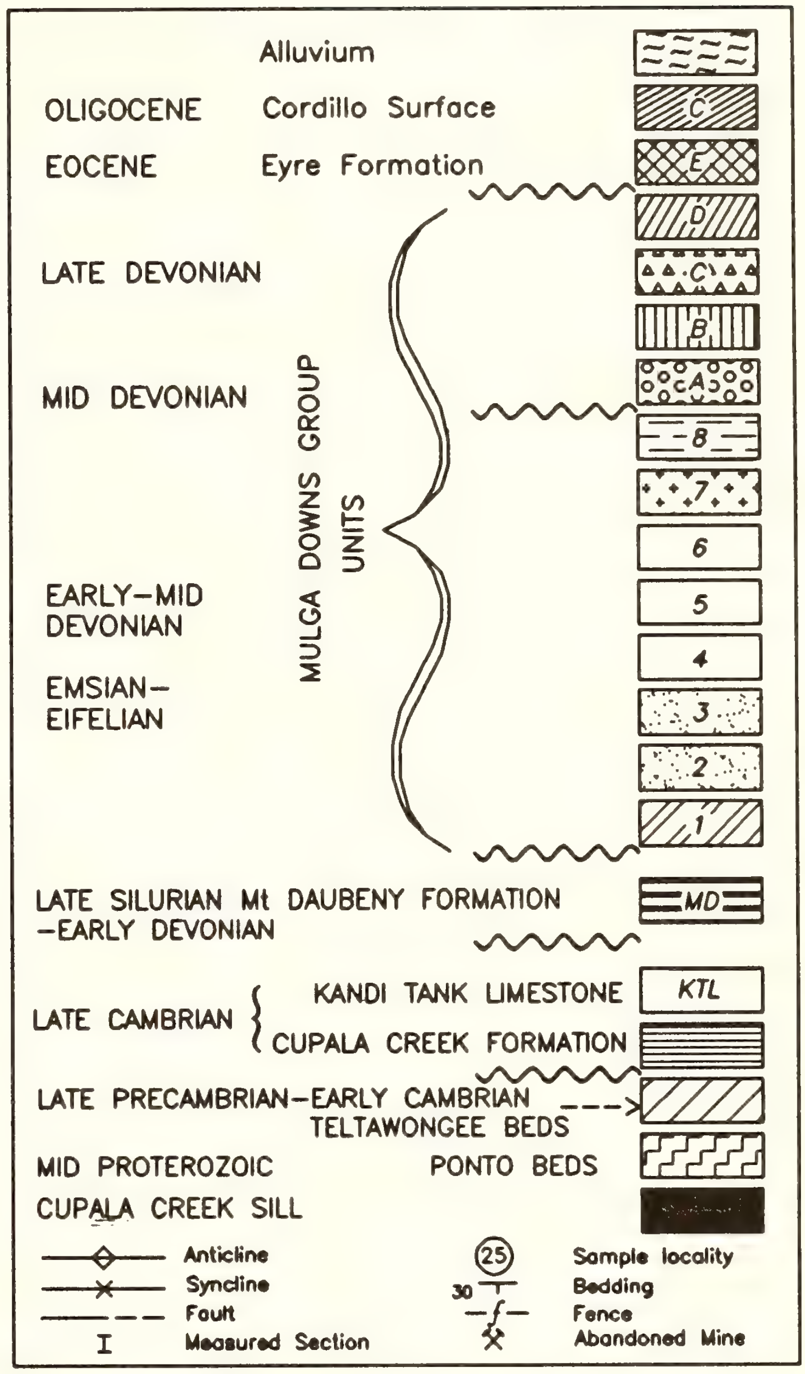


Figure 2. Geology adjacent to the Koonenberry Fault and south of Copper Mine Range and Key to Figure 1-3,8,9, and 11.

Ranges; and Early-Mid Cambrian Teltawongee Beds. Ponto Beds crop out west of the Koonenberry Fault whereas Teltawongee Beds occur to the east of the fault.

?Emsian-Eifelian strata of the Mulga Downs Group in the Copper Mine Range are unconformable on Teltawongee Beds except near Cupala Creek where they are unconformable on the Late Cambrian Cupala Creek Formation (Powell et al. 1982).

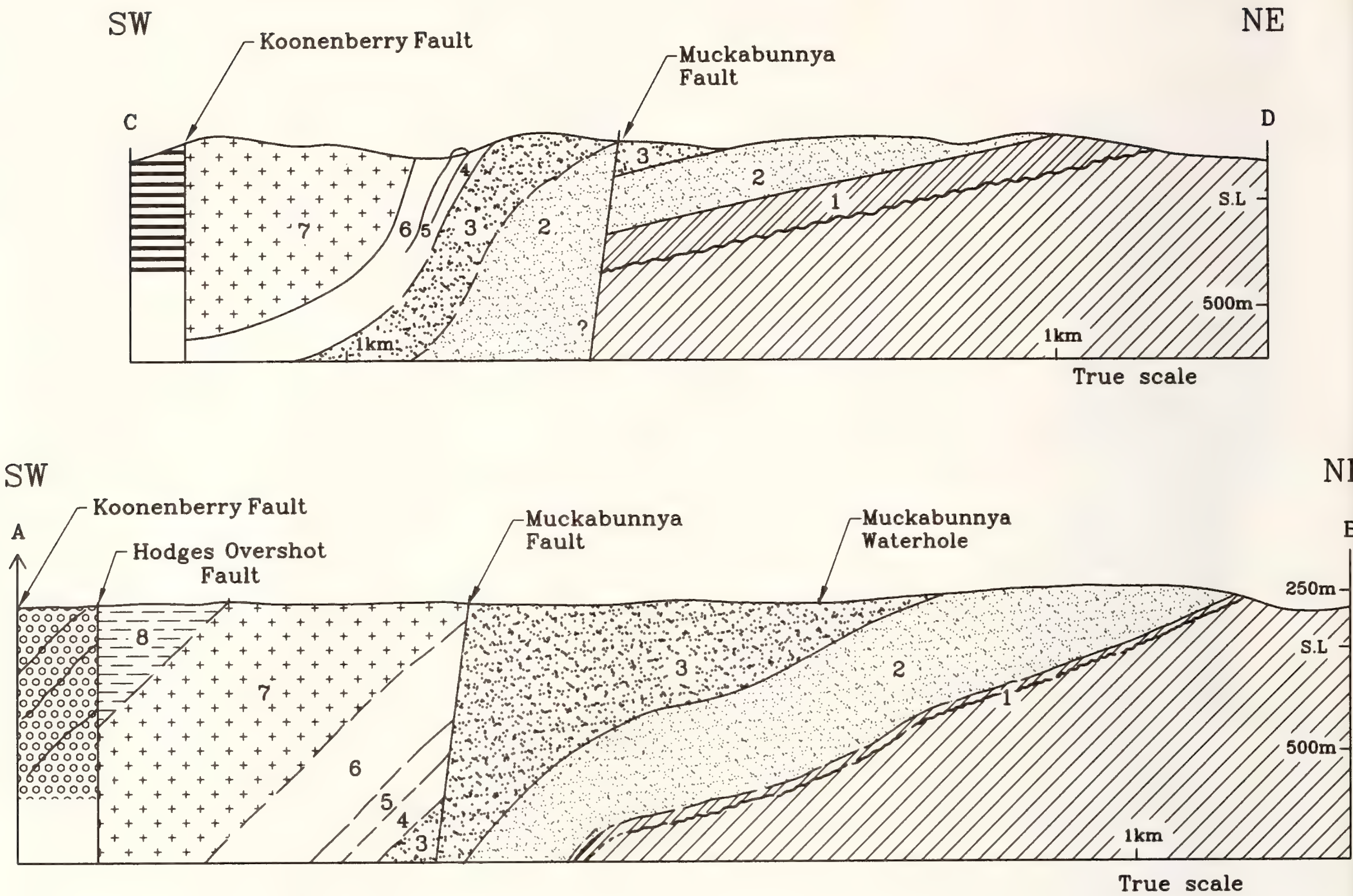


Figure 3. Geologic cross sections, A-B, C-D (for location see Figure 1).

South of Copper Mine Range ?Emsian-Eifelian strata overlie unconformably the Late Silurian - Early Devonian Mt Daubeny Formation, and Mid-Late Devonian strata unconformably overlie, ?Emsian-Eifelian strata. The Darling Basin began to form during the Late Silurian. Substantial deformation in the late Mid Devonian structured the basin into a number of sub-basins (troughs) that lie adjacent to horsts (Evans 1977) (Fig. 1, inset). The area mapped lies to the NW of the Pondie Range Trough.

The Mulga Downs Group is overlain unconformably by kaolinitic fine grained sandstone of the Paleocene-Eocene Eyre Formation.

STRATIGRAPHY

The stratigraphy (Fig. 4) is described in terms of two regions: a) Copper Mine Range to the north of Hodges Overshot (Fig. 1), and b) a sector south of Hodges Overshot as far as Mt Daubney (Fig. 2).

The typical constituent formations of the Mulga Downs Group are identified on the eastern flank of the Darling Basin, to the west and south of Cobar (Glen 1979). No formally named subdivisions of the group are identified in the Copper Mine Range area, although informal 'Units' are recognised.

The age of the Mulga Downs Group on the western side of the Darling Basin is based on rare fragments of fossil fish and (subsurface) a few occurrences of microspores. Two faunas and rare microspores, Emsian-Eifelian and Frasnian-Fammenian in age, are known (Neef et al. 1995). Unfortunately neither fossil fish nor microspores have been located in the Copper Mine Range where the age of strata assigned to the group is based on

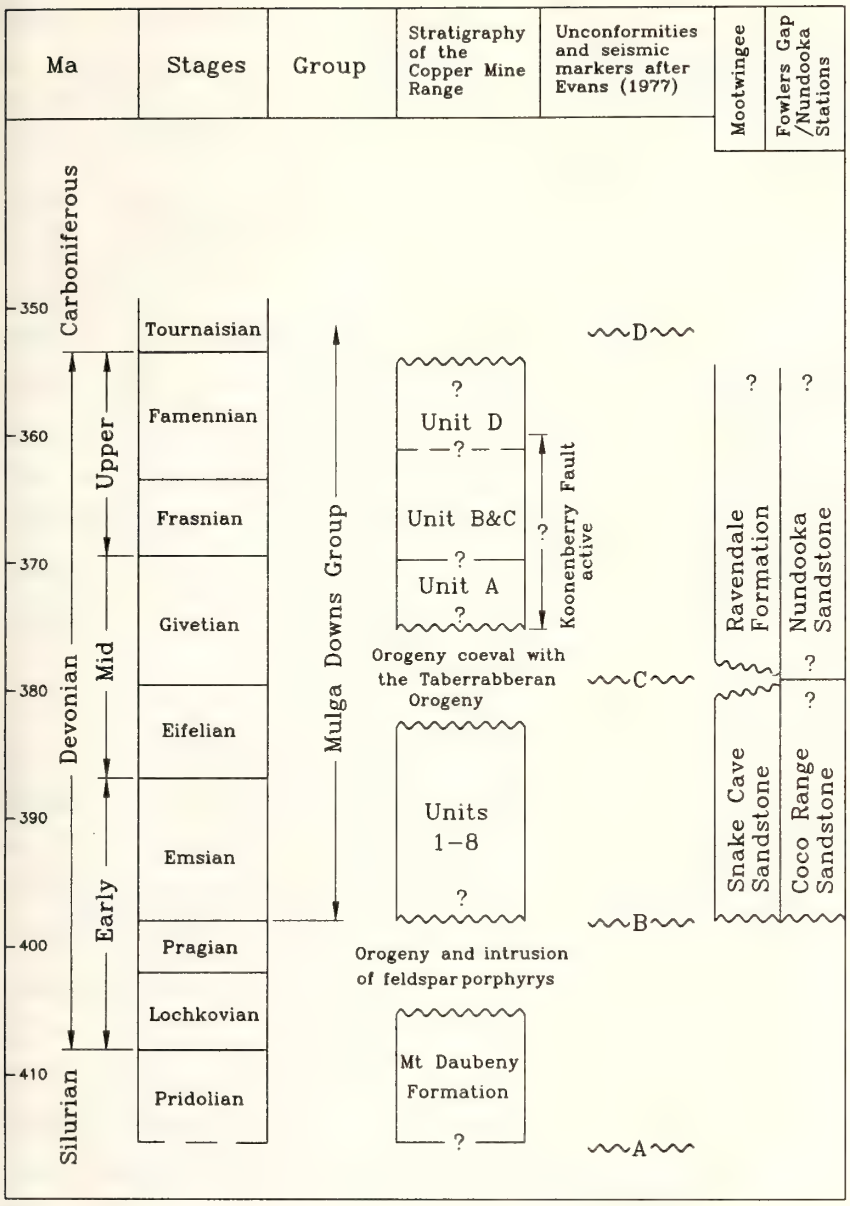


Figure 4. Silurian-Devonian stratigraphic succession of Copper Mine Range and south of the range tentatively correlated with the Devonian stages after Young (1989).

less certain criteria. Strata are much brecciated adjacent to the Koonenberry and Muckabunnya Faults. South of the range identical brecciated quartzose sandstones crop out in steeply dipping strata adjacent to the Koonenberry Fault. East of Gnalta Peak these brecciated strata are unconformably overlain by lightly indurated beds which are also referred to here as Mulga Downs Group (and elsewhere called Ravendale Formation). This relationship forms the basis for considering the strata of Copper Mine Range to be Emsian-Eifelian rather than Late Devonian in age. However there is a probable correlation of basal strata of Unit 2 of Copper Mine Range with Emsian-Eifelian strata of Unit 1 from the Coco Range Formation at Nundooka Station (Neef et al. 1995). This correlation follows from horizons of vertical burrows (?Skolithus sp.) lying 320 m and 330 m above the base of Mulga Downs Group at Nundooka Station and in the study area respectively.

A. COPPER MINE RANGE

Eight stratigraphic units are mapped within the Mulga Downs Group of the Copper Mine Range area (Fig. 5). They lack marker beds, have sheet-like distributions, and usually have abrupt basal contacts. An exception is Unit 1 which is unknown in the north and the east, indicating that the basal part of Unit 2 is diachronous, being older in the north and east than where it overlies Unit 1. On stereo pairs beds of Units 2, 3 and 7 have considerable continuity, forming minor ridges and depressions.

The sandstones, which show a gradual decrease of feldspar and lithic fragments content with age and lack plant fossils, are described using the nomenclature of Miall (1977) and Heward (1989) (i.e. Sh, laminated sandstone; St, trough cross bedded sandstone; Sp, planar cross bedded sandstone, Sr, rippled sandstone; Fl, overbank fines, and sm. massive sandstone).

Except for Unit 2, much of the ?Emsian-Eifelian succession is medium or coarse grained and thus palaeocurrent trends are less common than they are in Devonian strata at Fowlers Gap and Nundooka Stations, where finer grained sandstones are common (Neef, Bottrill and Cohen 1996). 107 palaeocurrent trends were measured in Units 1-8. Most palaeocurrent trends were measured NE of the Muckabunnya Fault; however 12 trends were measured on the Coturaundee Range, and 10 were measured near Hodges Overshot.

Unit 1 Basal massive sandstone: This unit (max. thickness 150 m) forms the base of the Mulga Downs Group in most of the cliffs along the east side of Copper Mine Range. The

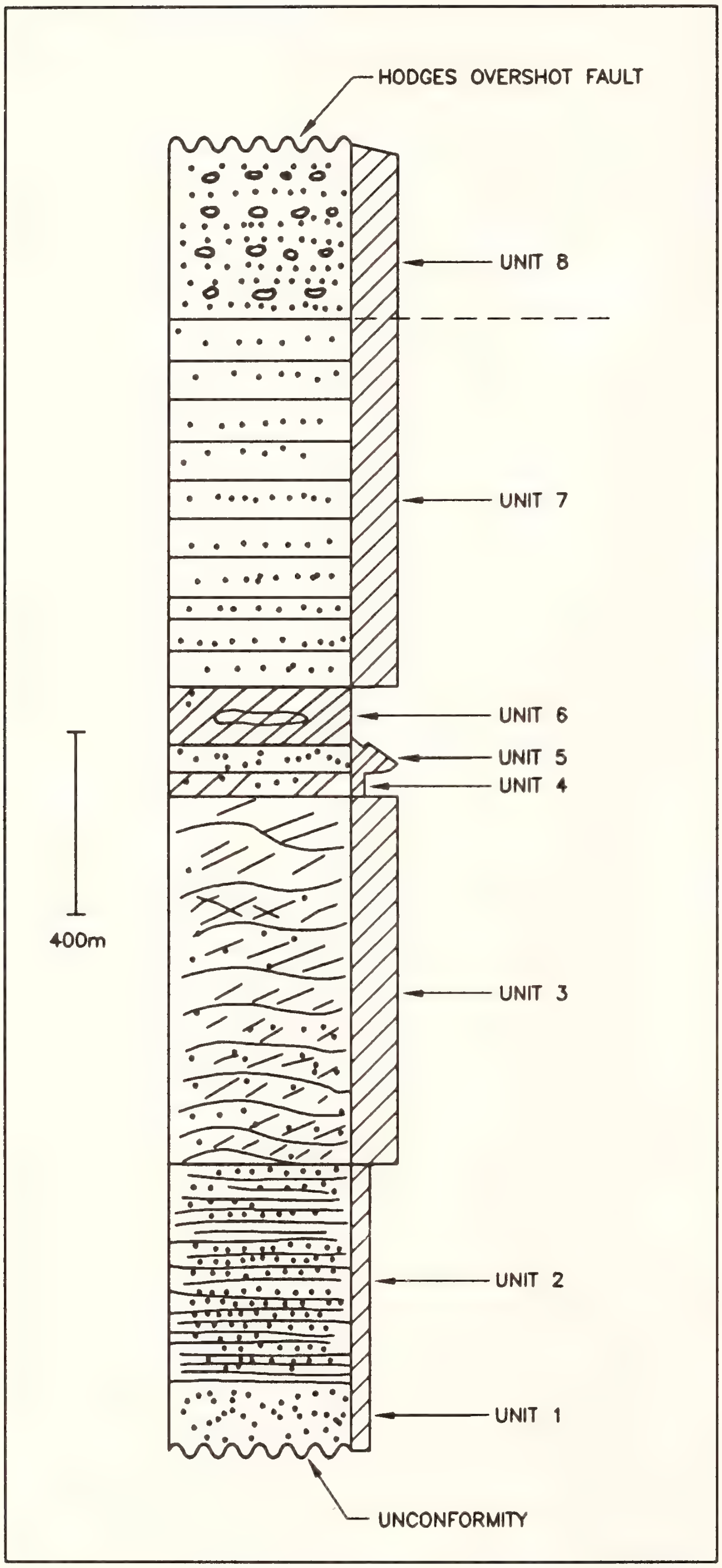


Figure 5. Emsian-Eifelian stratigraphic sequence of Copper Mine Range. Thicknesses of Unita 1-3 of the Mulga Downs Group are from stratal thicknesses east of the Muckabunnya Fault whereas thicknesses of Units 4-8 are from west of the fault.

unconformity underlying the unit is commonly 60 m higher in elevation than the adjacent plain.

The strata are commonly rusty weathering fine grained and planar bedded (Fig. 6). Bedding is usually thick (max. bed spacing 10 m) and there are minor conglomerate beds (max. thickness 2 m), a 5 m thin bedded sequence, planar cross beds, pebbles, and symmetrical ripple marks. Five kilometres SE of Spring Hill a 2 m thick, pale grey, lightly indurated, kaolinitic, very fine sandstone crops out near the base of the unit. Curved along the bedding are burrows, 5-10 mm wide and 90 mm long, and laminae of fine and coarse grains are quite common in basal beds east of Cupala Creek. Two measured sections in the basal beds have Sh-Sp lithofacies successions, (Fig. 6).

The unit is a mature quartz arenite (Fig. 7), well sorted, but with about 5-10% of clayey matrix (illite, kaolinite and minor silt). There are 1-3% of kaolinite aggregates, apparently pseudomorphous after feldspars, and a few percent of lithics (ranging from micaceous quartzite to schist, phyllite, sandstone, chert and mudstone). The matrix appears to originate in part from post-depositional degradation of feldspars and lithics. Diagenesis and low grade metamorphism has part recrystallised the matrix and caused quartz overgrowths to form on originally well rounded quartz. The overgrowths are partly polygonal or terminated in empty and clay-filled cavities, and there is evidence for at least two stages of overgrowth on some grains. This indicates at least two periods of erosion, deposition and lithification. Trace minerals include white mica, tourmaline, zircon and leucoxene.

Absence of basal conglomerates is common in the Mulga Downs Group (Neef et al. 1995) and the Mt Daubeny Formation (Neef et al. 1989). The implication is that deposition of the basal sandstone beds followed a period of peneplanation and that deposition was distal from the sediment source. The thickly bedded massive cliff-forming strata along the east side of Copper Mine Range are fluvial; the Sh-Sp succession near Cupala Creek (Fig. 6) indicates minor sheet flood deposition (as described by Neef, Bottrill and

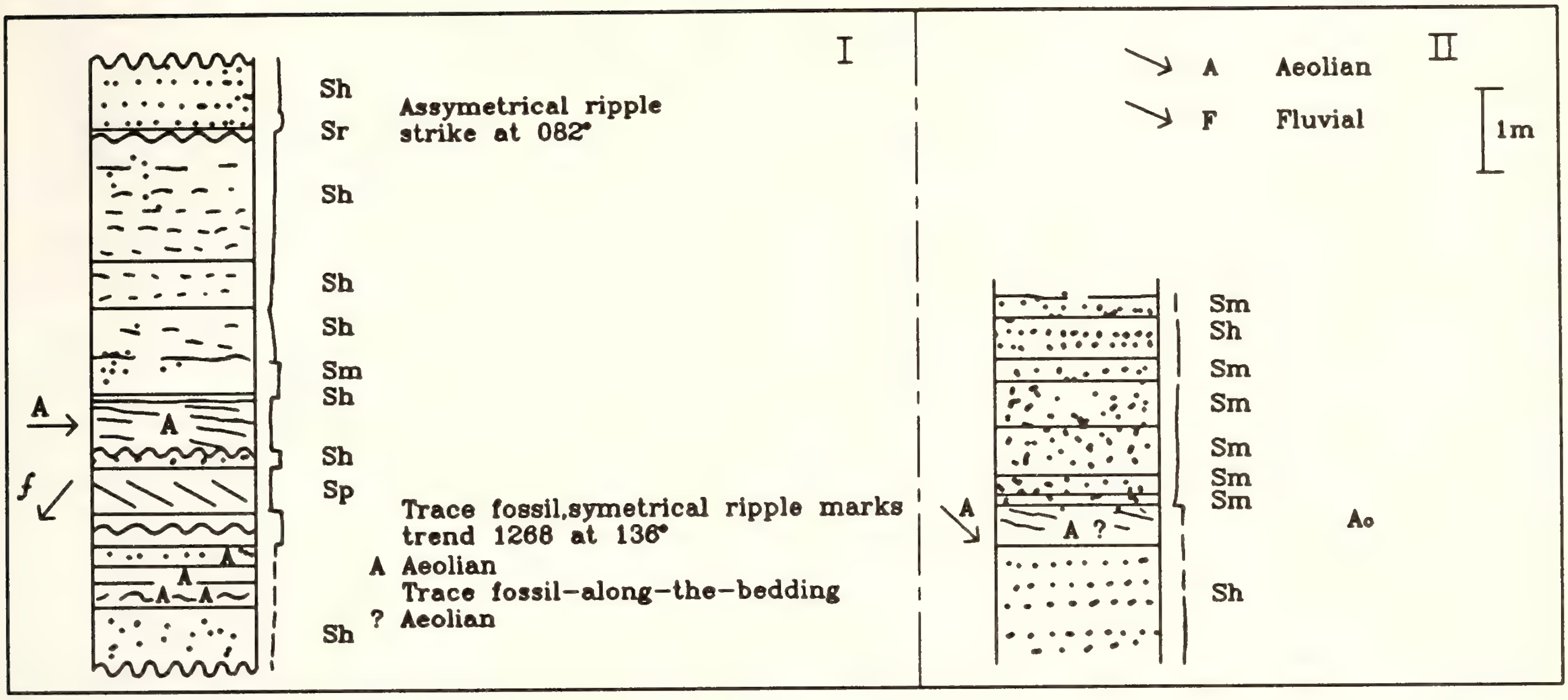


Figure 6. Lithofacies sections I and II in Unit 1 in the headwaters of Cupala Creek, (for location see Fig. 1). Nomenclature after Miall (1977) and Heward (1989).

Cohen 1996). East of Cupala Creek laminae of fine and coarse sandstone, worm burrows parallel to bedding, low angle cross beds, and a thin-bedded sequence indicate deposition in a part aeolian environment. Fluvial palaeocurrent trends were largely southwards (Fig. 8). Rarity of overbank deposits suggest a braided stream system with mobile channels (Friend 1983). Perhaps deposition was partlyon a southward-trending distal alluvial fan.

Unit 2. Fine laminated quarkose sandstone: These strata form the base of the succession in the northern and eastern parts of Copper Mine Range. The unit is well developed on the Coturaundee Plateau, north of Muckabunnya Waterhole, and along Hummocks Fault at Spring Hill. Characteristically it is very fine or fine grained, medium sorted and quartz-rich. It is petrographically similar to Unit 1, but contains a little more feldspar (all kaolinised). Streaming lineations are common whereas planar cross beds are rare. Sheet flood successions described in the northern Barrier Ranges (Neef et al. 1995) were not seen. Indeed minor slumped strata overlie unslumped laminated strata. Near the base of the unit there are 5-10 m thick beds with common vertical burrows of ?Skolithus sp. (0.3 m deep and 5mm in diameter) (first reported in the headwaters of Cupala Creek by Rose 1974). From this locality the beds with burrows extend 8 km and 1.5 km to the north and south respectively. There are beds with and without burrows at the latter locality. ?Skolithus sp. is also known near the base of the unit 2.5 km south of Spring Hill.

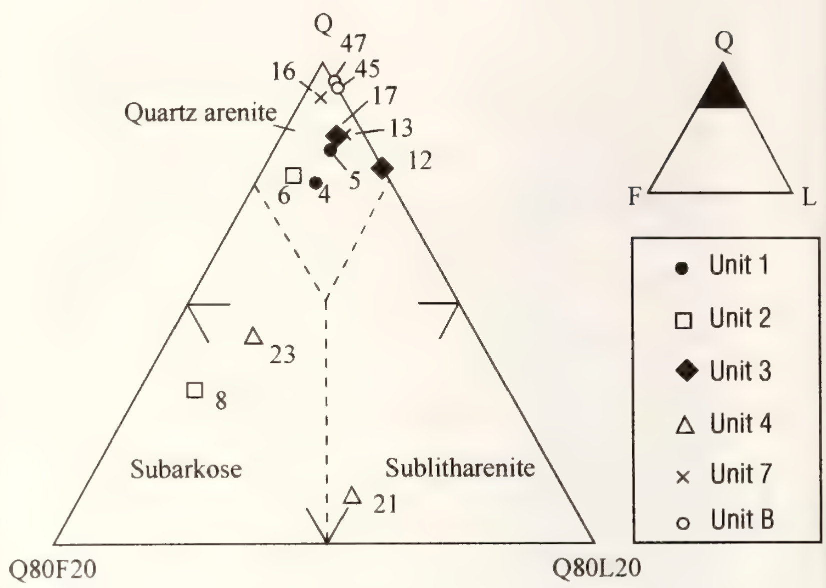
Northwest of Muckabunnya Waterhole are three, 2-4 m thick, 1 km-long sequences of lightly indurated pale-grey, kaolinitic, fine grained sandstones. North and NW of the waterhole the upper part of the unit is much slumped. East of Muckabunnya Fault the unit is 500 m thick (Fig. 3, section A-B).

Abundant Sh lithofacies and common streaming lineations (46 palaeocurrent trends were measured) indicate deposition mainly in a high flow regime (Tunbridge 1981) and it is probable that deposition was during flash floods of Bijou Creek style (McKee et al. 1966). Such floods are typical of ephemeral streams (Miall 1977) and the unit probably represents distal braid plains with

flashy discharge (model 12 of Miall 1985). Also present, but uncommon are 1 km-wide overbank areas, which are now represented by the lightly indurated kaolinitic fine grained sandstone. Absence of sheet flood successions indicates that the braid plains had lower gradients than the coeval alluvial fan deposits of Nundooka Station (Neef, Bottrill and Cohen 1996). Common slumping in the upper part of the unit may follow drag caused by a subsequent flash flood, or they may be due to penecontemporaneous earthquakes on any one of the nearby faults. The fine grained uniform sandstone indicates sediment derivation was from fine grained sandstone like the Cupala Creek Formation, or was from distant regions. Palaeocurrent trends indicate dominant ESE and WSW flow (Fig. 8). Two planar cross beds in the uppermost part of the unit indicate eastward flow and one in the lower part indicates WSW flow. At several localities one dimensional profiles indicate an eastward flow component and it is considered that ESE flow was dominant.

There is a marine component in the Emsian-Eifelian fish fauna at Mt Jack (north of Wilcannia) (Neef, Larsen and Ritchie 1996), and the ?Skolithus horizon in Unit 2 may indicate a marine influence.

Unit 3 Pebbly medium and coarse grained sandstone: This unit crops out along the axis and the east limb of Cootawundy Syncline and it is well developed near Muckabunnya Waterhole. It comprises well sorted, subrounded, medium and coarse grained, rusty weathering sandstone. Invariably bedding is difficult to determine and channelling was noted at one locality only. Scattered rounded and subangular vein quartz and quarzite pebbles (max. clast length 80 mm) rarely form more than 1% by volume of the unit. Lithofacies sequences were unrecognised. Sets of tabular cross beds have a maximum thickness of 2 m. The unit is at least 850 m thick east of Muckabunnya Fault (the top part of the unit is faulted out), whereas it is only 250 m thick west of the fault.



SAMPLE	Q	F	L	%MATRX	UNIT
CMR4	95.0	2.9	2.1	5.1	1
CMR5	96.5	1.6	2.0	9.8	1
CMR6	95.3	3.6	1.1	9.6	2
CMR8	86.4	11.7	1.9	6.0	2
CMR12	95.7	0.0	4.3	12.0	3
CMR13	96.9	0.8	2.2	1.8	7
CMR16	98.5	0.9	0.7	7.8	7
CMR17	96.8	1.3	1.9	4.8	3
CMR21	82.1	8.2	9.7	17.4	4
CMR23	88.7	8.4	2.9	10.6	4
CMR45	98.9	0.0	1.1	10.8	B
CMR47	99.2	0.0	0.8	0	B

Figure 7. QFL diagrams of arenites from ? Emsian strata of Coppper Mine Range and from the Late Devonian strata south of Copper Mine Range. QFL proportions of framework quartz, feldspar and lithics normalised to 100%. 500 counts per section.

The arenites are petrographically similar to Unit 1, but contain less feldspar (now all kaolinised). Some of the quartz is finely rutilated and a grain of tourmalinite was observed. The latter rock type is important in the Broken Hill area, as is the rutilated quartz, indicating a sediment source area including Willyama Complex. Recycled, well rounded quartz grains are common.

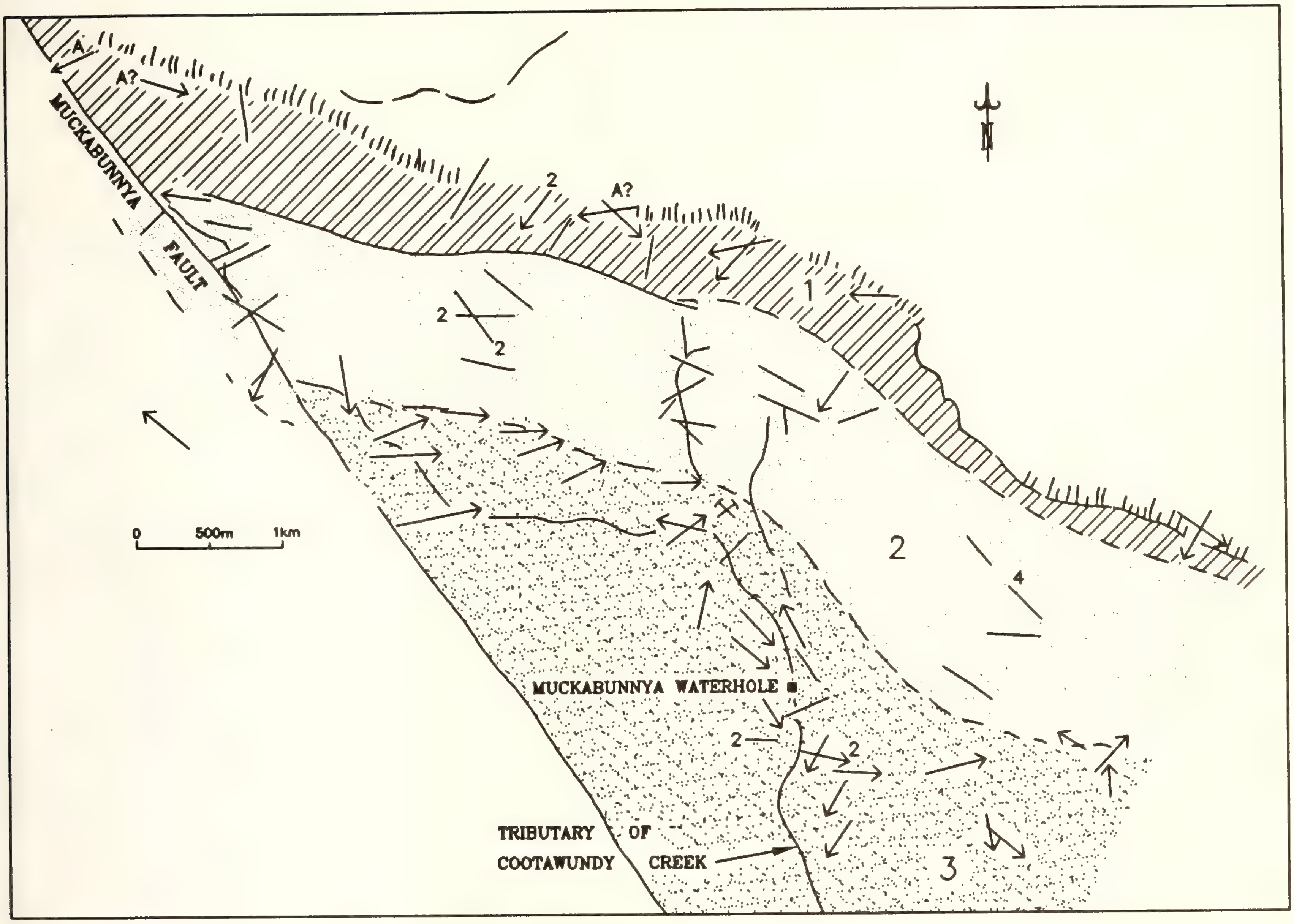


Figure 8. Palaeocurrent trends, in Units 1, 2 and 3, near Muckabunnya Waterhole. Key: see Figure 2.

Absence of overbank deposits indicates deposition within a low sinuosity stream system. Fines were flushed through the system, suggesting that deposition was on the bed of a high gradient river (like the deposition of some very thick, uniform, pebbly sandstones of the Devonian of Greenland and Spitzbergen, P. Friend pers. comm. 1995). Difficulty in determining bedding suggests that the beds of the braided streams that deposited the unit were commonly floored by dunes and bars. That is, the unit represents a sandy bed form (S.B. of Miall 1985). Maximum cross-bedding thickness of 2 m indicates that deposition was in very shallow streams/rivers. Uniformity of the coarse-grained lithology suggests stability of climate and sustained uniform uplift and erosion in the hinterland. Tabular cross beds show that palaeoflow trends had both north and ENE components in the lower part of the unit (15 readings, Figs. 8 and 9). in contrast the middle and upper parts of the unit indicate SE and SW flow (15 readings). it is thought that the unit represents a Platte type river style of deposition (Miall 1977).

Unit 4 Brown and red poorly sorted sandstone: Pale red and pale brown poorly-sorted, lightly-indurated, arkosic, micaceous sandstone, 50 m thick, crops out along the axis and eastern limb of Cootawundy Syncline. Lamination (Fsc, Miall 1978) is well developed in many outcrops.

In composition this unit ranges from a subarkose to a felspathic quartzwacke (Figure 7), and it is petrographically quite distinct from other

units, containing much more feldspar (7 %), and having a clay matrix (10-18 %) and up to 8 % lithics (mostly schist, sandstone and mudstone). The feldspar is relatively fresh, and is predominantly orthoclase, with minor plagioclase and microcline. Mica (mostly muscovite and some green-brown, altered biotite) and opaques are relatively abundant, and there is a trace of tourmaline. Perhaps the feldspars have been preserved due to the low permeability of the clay matrix. Some of the quartz is rutilated, micaceous or fibrolitic, and the Willyama and Wonaminta Blocks are probable sources of the sediment.

Common lamination (Fsc) is of the low flow regime style and much of the unit represents overbank deposition on a broad alluvial plain.

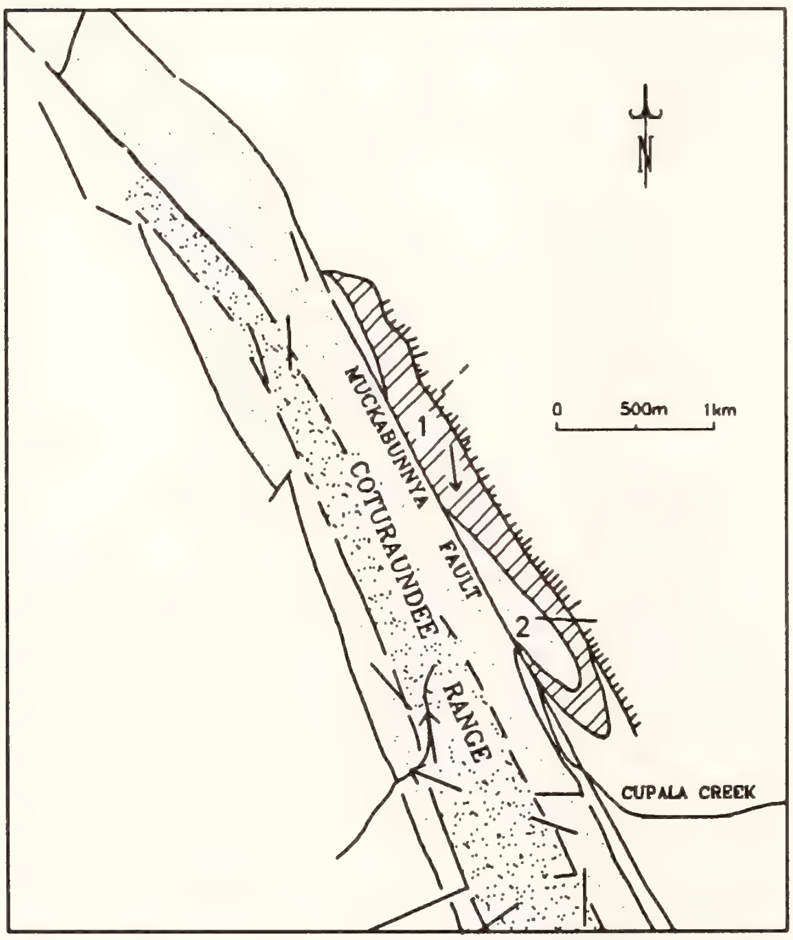


Figure 9. Palaeocurrent trends, in Units 1, 2 and 3, on the Coturaundee Range. Key: see Figure 2.

Unit 5 Quartzose sandstone: This unit, petrographically similar to Unit 1, has a strike length of 6.5 km along the north margin of Cootawundy Valley. It comprises sheet-like, planar bedded, coarse, medium and fine grained sandstone with scattered pebbles (<1% by volume). Commonly the upper part of the unit is fine grained and laminated and shows streaming lineations. It is 71 m thick in the measured section 1.5 km north of Great Wertago Mine (Fig. 10), where there are three pebble lag horizons, whereas it is only 56 m thick 1.5 km to the SE.

Absence of overbank deposits indicate high gradient, low sinuosity flow. Rarity of low flow regime features such as cross bedding and ripple marks and the presence of streaming lineations in its upper part suggest much deposition in a high flow regime (flood environment) . However, the three pebble lags of the measured section indicate deposition from perennial streams. A cross bed indicates eastward flow whereas the streaming lineations are consistent with a SE flow trend (Fig. 11). Deposition was probably on a distal braid plain (Model 11 of Miall 1985).

Unit 6 Red brown and grey green very fine sandstone and shale: This unit, 120 m thick, is poorly exposed along the banks of Cootawundy Creek. It is largely composed of moderate reddish-brown, poorly sorted, slightly micaceous, very fine sandstone and shale. Also present are poorly sorted, coarse, olive grey, slightly micaceous (max. thickness 12 m) sandstone and shale.

The strata formed as a result of overbank deposition upon a broad alluvial plain, the red-brown mudstone being oxidized facies and the grey-green mudstone the product of a reducing environment. The sandstone successions have, perhaps, a crevasse-splay origin.

Unit 7 Coarse, medium and fine grained pebbly sandstone: This unit has a 1.5-2 km wide, 6 km long outcrop north of Hodges Overshot. It is 870 m thick and best exposed in the gorge of Gnaltaknoko Creek. It commonly forms 50 m wide, 10 m high strike ridges which alternate with 50 m wide strike valleys. The strata are poorly sorted, planar bedded, coarse, medium and fine grained pebbly sandstones (pebbles have a maximum length of 80 mm). Planar cross beds are

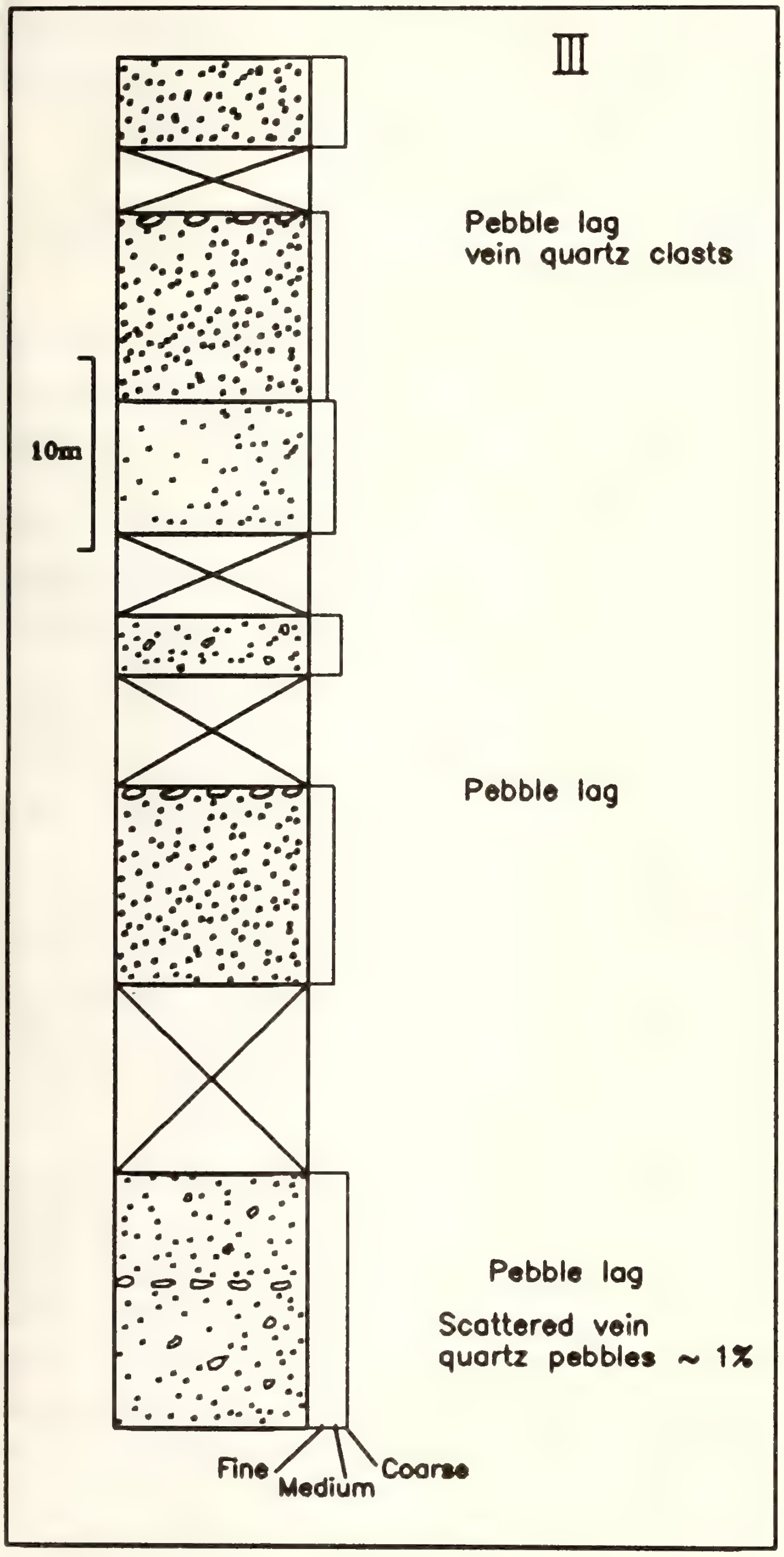


Figure 10. Lithology log of Unit 5 in Cootawundy Creek (for location see III in Figure 1).

rare and trough cross beds and ripple marks are absent. One desiccation structure was found. There are minor coarse and fine grained laminae in the basal part of the unit.

The unit is petrographically similar to Unit 1, but contains less lithic grains. There is a little rutilated

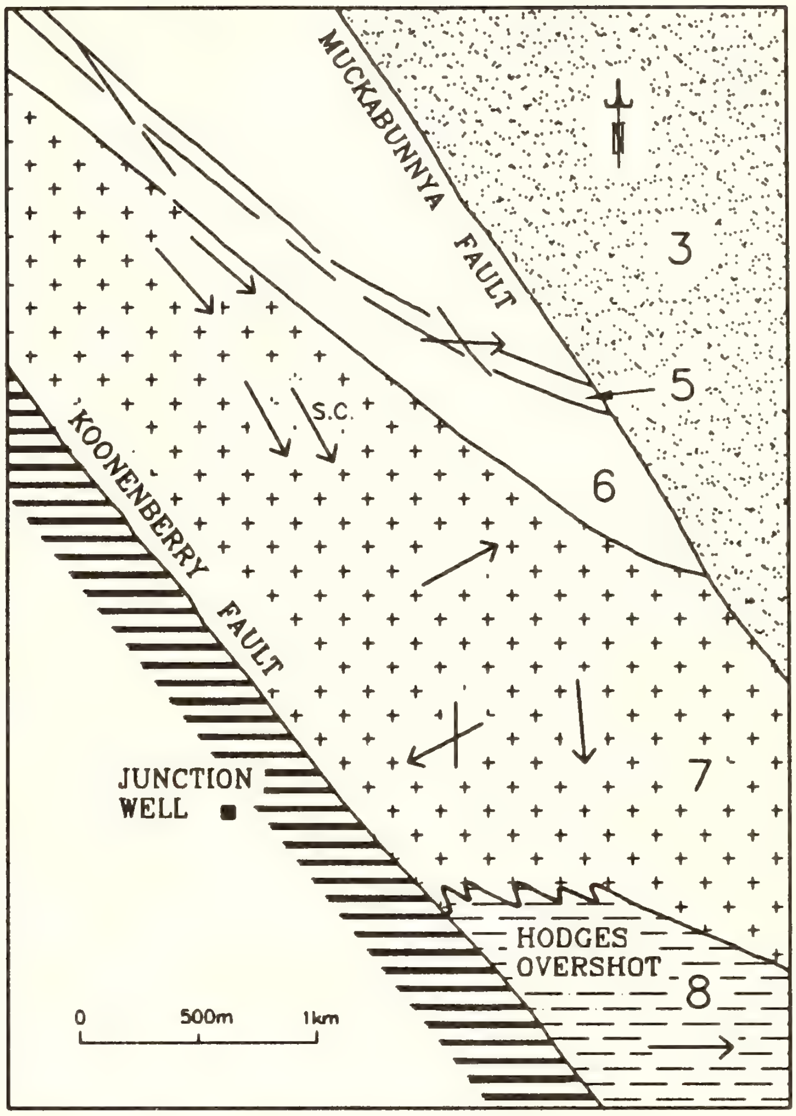


Figure 11. Palaeocurrent trends, in Units 5, 7 & 8, near Hodges Overshot. Key: see Figure 2.

quartz and fibrolitic quartz, both characteristic of the metamorphic rocks of the Willyama Complex. Petrographic study indicates that some grains have been recycled from older sedimentary strata.

Absence of overbank fines suggests deposition in a high gradient river system. Well developed bedding shows that deposition was on the beds of streams that had little relief. Pebble lags indicate at least some fully perennial flowing streams. The coarse and fine grained laminae indicate minor aeolian deposition. Palaeocurrent trends were dominantly southeastwards (Fig. 11).

Unit 8 Coarse and fine laminated sand with pebble lags: This unit, which crops out near Hodges Overshot, is >550 m thick (its top is

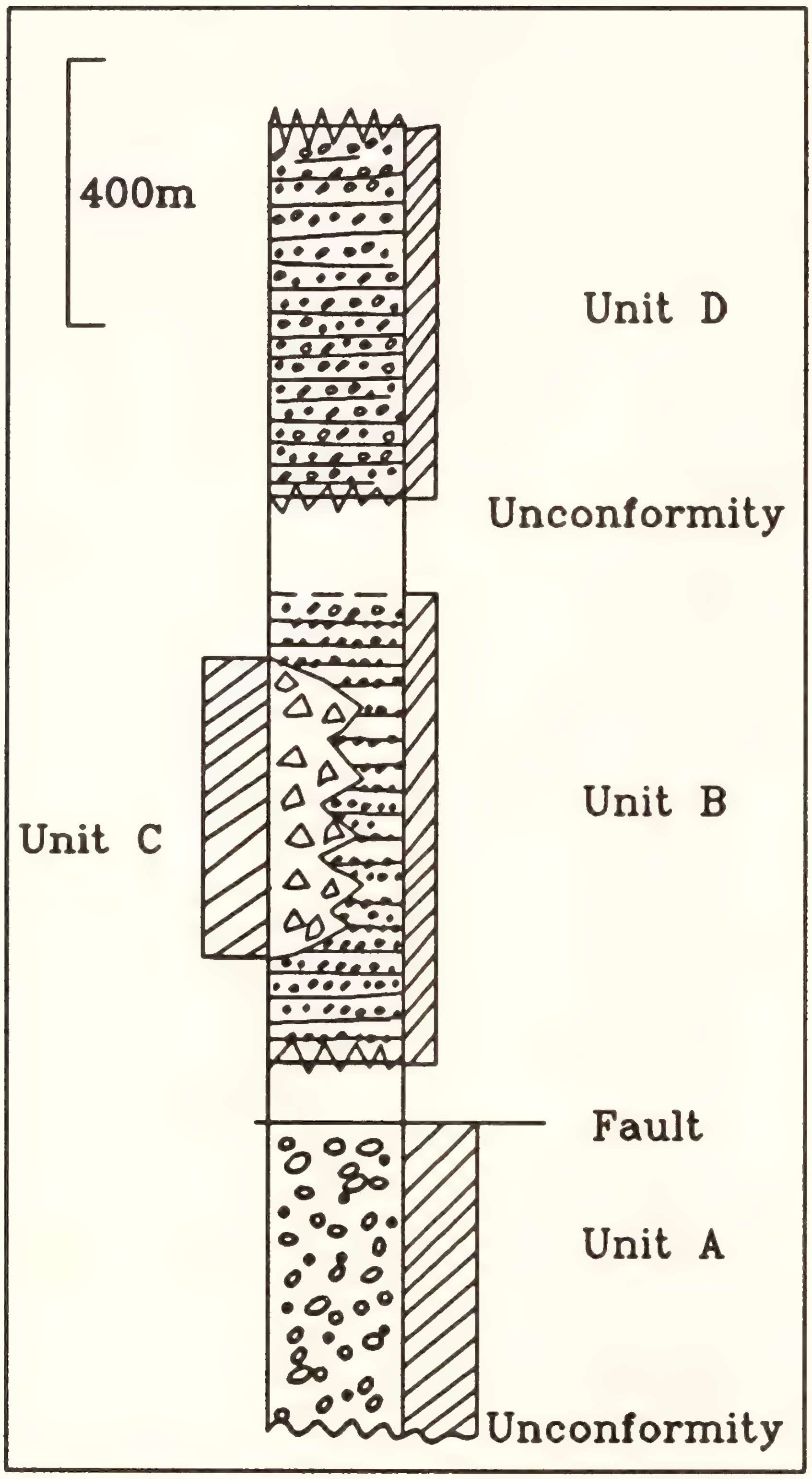


Figure 12. ?Late Mid Devonian-Late Devonian stratigraphic units south of Copper Mine Range.

faulted out by Hodges Overshot Fault). it comprises alternating coarse and fine unrippled sandstone with pebble lags (max. Cast size 70 mm) that occur at 0.25 m intervals.

Some aeolian deposition is indicated by laminae of fine and coarse grains and the presence of gravel lags. This type of deposition is common in areas where there is an abundant coarse grained fraction, (Kocurek and Nielson 1986). Generally, modern sand sheets are <10 m thick and they may be rippled or unrippled; thus the substantial thickness of Unit 8 implies a dual fluvial/aeolian deposition. Sand sheets are known to form upwind of dune fields (Kocurek and Nielson 1986).

B. SOUTHERN SECTOR: K-LINE TO HODGES OVERSHOT

Lightly indurated ?Late Devonian strata are exposed in a 20 km long, 2.5 km wide belt east of the Koonenberry FauH and north of the track between Mt Daubeny Outstation and K-Line Station (Fig. 2). The Late Devonian strata unconformably overlie the Mt Daubeny Formation and brecciated steeply dipping indurated ?Emsian-Eifelian strata.

?EMSIAN-EIFELIAN

At the eastern margin of Koonenberry Fault lies a north-trending, 300-500 m wide belt of moderate to steeply dipping,indurated, brecciated, commonly quartz net-veined, quartzose sandstone. These strata are taken to represent Units 1 and 2 of Copper Mine Range. East of Gnalta Peak they form a 1.3 km wide outcrop that is bounded by the Gnalta Peak and Gnalta Creek Faults. Locally within the strata there are rare sedimentary breccias and one pale red sandstone bed. North of Gnalta Peak Fault lies a belt of steep eastward-dipping quartzose sandstone with conglomerate lenses (max. thickness 2 m). The clasts forming the conglomerate lenses are of vein quartz and quartzite (max. clast length 0.11 m). Similar strata crop out in a 300 m-wide fault sliver along the Koonenbery Fauit near Mt Daubeny Outstation - K-Line track.

?MID-LATE DEVONIAN

Four fluvial units, A, B. C and D are mapped (Figs. 2 & 12). on stereo pairs (June 1965) Unit B has well developed strike ridges (like those of Units 2, 3 and 7 of Copper Mine Range) whereas the strike ridges of Unit D also show much lateral continuity, but they are not as bold as the ?Emsian-Eifelian strike ridges.

Unit A Sandy conglomerate: Unit A lies between the Gnalta Peak and Gnalta Creek Faults. It is >450 m thick (top faulted out) and is unconformable on folded ?Emsian-Eifelian strata. Clasts, largely of quartzite, (max. length 0.2 m), are subangular to subrounded. The strike of the unit is northerly distant from Gnalta Peak whereas near Gnalta Peak it is westerly.

Between Koonenberry and Hodges Overshot Faults there is a 850 m-wide, 2.5 km-long, 600 m thick belt of massive conglomerate (max. clast length 0.25 m). A Cambrian age for this conglomerate was previously preferred because similar thick Cambrian conglomerate crops out near Bilpa (100 km to the SSW) and Koonenberry Mountain (60 km to the NW) (Neef et al. 1989). However, this conglomerate, and a fault sliver of conglomerate found 3.5 km north of Great Wertago Mine, are now attributed to Unit A.

The conglomerate formed after the deformation represented by seismic marker C of Evans (1977). it may be Givetian and coeval with a coarse conglomerate of the Cobar District (Powell 1984, p.320).

Floods emanating from west of the Koonenberry Fault carried small boulders, cobbles, pebbles and sand eastwards to bury a hilly, late Mid Devonian topography. Absence of boulders >0.25 m indicates that the clasts were transported at least a kilometre or two. The unit represents alluvial fan deposition (Model 2 of Miall 1985).

Unit B Rusty weathering sandstone: Plane-bedded, commonly fine grained sandstone crops out adjacent to the track between Mt Daubeny Outstation and K-Line Station, and extends 5 km northwards from the track. Locally there are medium and coarse grained sandstones, pebble lags and rare tabular cross-bedding. Pebbles are commonly of vein quartz and quartzite. In the north, the beds contain scattered clasts derived from Ponto Beds and there are rare 0.5 m thick conglomerate beds (max. clast size 100 mm). The unit is at least 700 m thick - its upper part being faulted out by Gnalta Peak Fault.

The unit (a quartz arenite, Fig. 7) differs from the ?Emsian-Eifelian strata in lacking feldspars or kaolinite pseudomorphs after feldspars, and being porous and weakly silicified, with little compaction. Quartz is well-rounded and quartz overgrowths are present, but not to the extent of those developed in the ?Emsian-Eifelian units. The matrix is a network of illite coating, quartz and pores. There are traces of phyllite, chert, tourmaline, mica and zircon. The porosity is 10-12%, indicating that the unit is a potential aquifer.

The unit is younger than Unit A and is thought to be Frasnian-Fammenian in age.

In lithology and sedimentary features the unit resembles Units 5 and 7 of Copper Mine Range although pebble lags are not as prominent. Palaeocurrent trends, indicated by two tabular cross beds in the uppermost part of the unit, are easterly (mean 083°) and a streaming lineation is consistent with a flow direction of 070°.

Unit C Intraformational breccia: Plane-bedded, matrix-supported breccia comprising subangular clasts of lightly indurated sandstone (max. clast length 0.3 m) crop out on a 0.75 km wide, 2.5 km-long, NE-trending belt within Unit B. The unit, which has an abrupt basal contact, is 450 m thick, and wedges out northwestwards. The clasts lack imbrication and no tabular cross-beds were found.

From its distribution adjacent to Koonenberry Fault, and because some of the largest clasts are found adjacent to the fault, the unit is considered to be derived from lightly indurated sandstone previously deposited west of the fault.

Unit D Fine grained sandstone: Unit D crops out north of Gnalta Peak Fault. It is uniformly inclined 20˚ to the northeast and >550 m thick. The unit is largely a plane-bedded, fine grained

sandstone with minor tabular and trough cross-beds and streaming lineations. There are rare clasts of vein quartz and quartzite. The formation resembles the Ravendale Formation found west of the Koonenberry Fault.

Three palaeocurrent trends within the unit indicate NE flow (mean 60˜), suggesting that the depocentre during the Late Devonian was to the NE (near White Cliffs). Deposition was within a widespread braided stream system.

From its outcrop distribution the unit probably formed subsequent to the growth of the Menamurtee Dome (i.e. it is younger than Units B and C).

STRUCTURE

The study area has several faults (most trend NNW, and two important folds. Minor faults are virtually absent, except in areas adjacent to the major faults, and minor folds are very rare.

KOONENBERRY FAULT

The major NNW-trending, 300 km-long Koonenberry Fault (Wilson 1967; Brunker et al. 1971; McIntyre 1991) probably extends from northern NSW south to the Barrier Highway (Wilson 1967). Mills (1992) thought the fault to be a dip-slip fault (upthrown to the west) whereas Evans (1977) considered that it was sinistral during the Devonian. It is subvertical near the Great Wertago Mine and it is distinctive on stereo pairs, lying at a break in slope at the western margin of the Coturaundee Range. North of the mine are several fault slivers of Mt Daubeny Formation and one of Unit A, indicating that the fault has had a transtensional history. North of the mine, a sub-parallel fault lies 200 m to its east and extends northwards for 6.75 km.

HODGES OVERSHOT FAULT

The Hodges Overshot Fault diverges from the Koonenberry Fault south of Hodges Overshot and probably extends 12 km SSE as far as GnaHa Creek.

GNALTA PEAK FAULT

The NE-trending Gnalta Peak Fault (first mapped by Frenda 1965) separates Unit A strata north of the fault from NW dipping strata of Unit B south of the fault.

GNALTA CREEK FAULT

This fault trends subparallel to and lies 1.5 km to the NW of the Gnalta Peak Fault. It became inactive during the Late Devonian.

MUCKABUNNYA FAULT

The Muckabunnya Fault (Rose 1974) lies subparallel to Koonenberry Falt and 2 km to its east. Near Cupala Creek it has a 3 m-wide fault zone comprising intensely brecciated quartzose sandstone. Eight kilometres to the north the fault zone it is 1.15 m wide, dips 82˜ to the west and has slickenlines that dip 5˜ to the north. Slickensteps along its western margin show that the last movement of the fault zone was sinistral. Change of strike adjacent to the fault 2 km west of Muckabunnya Waterhole in Units 2 and 3 also indicates a sinistral displacement. The apparent sinistral offset of the Unit 2-3 contact is 0.7 km.

HUMMOCKS FAULT

At Spring Hill the NW-trending Hummocks Fault lies 4 km east of Muckabunnya Fault. At this locality there is a 700 m long, 80 m wide sliver of Unit 2 along its trace. The fault may die out SE of Spring Hill.

COOTAWUNDY SYNCLINE

Cootawundy Syncline (Rose et al. 1964) lies 500 m east of Koonenberry Fault and its axis extends 14.5 km along Coturaundee Range. In the north the strike of the fold swings northeastwards towards the Koonenberry Fault. East of Great Wertago Mine strata of Unit 5 are overturned in the west limb of the fold.

NORTHERN ANTICLINE

In the northern part of Copper Mine Range a NW-trending anticline lies 2.5 km west of Bunker Tank.

MENAMURTEE DOME

The NE-trending Menamurtee Dome is well developed on Moona Vale Station (Frenda 1965, Neef, Larsen and Ritchie 1996) and in the study area abuts Gnalta Peak Fault.

UN-NAMED FOLD

A large-scale, gentle SW-plunging syncline is apparent near Muckabunnya Waterhole.

GEOLOGICAL HISTORY

EMSIAN-EIFELIAN

Prior to the deposition of the Mulga Downs Group there was some minor deformation within the Darling Basin. Subsurface this deformation-unconformity event is represented by seismic horkon B (Evans 1977). Petrological studies indicate sediment derivation of Units 1-8 partly from lightly consolidated sandstones (perhaps strata such as the Cupala Creek Formation) and partly from metamorphic ?Wiilyama terrains. The grains of ?Willyama origin may have hadprevious residence in strata of the Wonaminta Block prior to being recycled (K. Mills pers. comm. 1996). Absence of pale red palaeosols in the thick Emsian-Eifelian succession indicate almost continuous deposition. The units lack sheet-flood successions, clay pellets, and small spherical bodies like those common in Emsian-Eifelian strata of the northern Barrier Range (Neef, Bottrill and Cohen 1996), indicating that the depositional site was distant from where the sediment was derived. Unit 1, formed of mature quartz arenites, probably represents deposition on a distal alluvial fan, which grew southwards. Unit 2 formed from ephemeral rivers, flowing largely SE on a braid plain. An abrupt change to eastward and northward flow in the lower part of Unit 3 may indicate a brief period of local uplift to the west of the Muckabunnya Fault. Unit 3 represents a period of bed load deposition, whereas the wash load was carried SE to the Pondie Range and Blantyre Troughs. The fine grained Units 4 and 6 suggest more distal deposition with the development of wide flood plains and the presence of meandering streams and rivers. The sandstone-rich Units 5 and 7 formed from floods and they may indicate uplift of the hinterland (or renewed basin subsidence). The aeolian influence in Unit 8 may owe its origin to the rise of the Wilcannia High to the south that separates Pondie Range Trough from Blantyre Trough. Rise of the Wilcannia High caused rapid filling of Pondie Range Trough (where Late Devonian strata are absent) and lower fluvial gradients The presence of substantially thicker strata of Unit 3 east of Muckabunnya Fault than to its west suggests syndepositional activity on the fault.

The Cupala Creek kimberlitic sill was emplaced soon after the Emsian-Eifelian succession was deposited and indurated, before the strata were folded (Bottrill and Neef in Prep.).

?LATE EIFELIAN - ?EARLY GIVETIAN

Coeval with the Tabberabberan Orogeny of eastern New South Wales considerable uplift and folding occurred in western New South Wales (Powell 1984). The Cootawundy Syncline formed at this time, indicating much NE-SW compression, and there was much brecciation of Emsian-Eifelian strata along the Koonenberry and Muckabunnya Faults. Deformation at this time is also known at Nundooka Station (Neef et al. 1995) and at Mootwingee (Carroll 1982). Subsurface in the Darling Basin this deformation event is represented by seismic marker C (Evans 1977).

?GIVETIAN

Unit A represents substantial alluvial fan deposition near a hilly or mountainous terrain (i.e. like the Delamerian conglomerates of Bilpa - Neef et al. 1989). Absence of large boulders and uniformity of clast size indicates transport of at least 1 km to the depositional site. The substantial thickness of the conglomerate suggests much syndepositional uplift of the source region.

FRASNIAN-FAMMENIAN

Most of the Mulga Downs Group east of the Koonenberry Fault resembles the Late Devonian Ravendale Formation near Mootwingee (Carroll 1982). Some of these Ravendale-like sandstones

deposited west of Koonenberry Fault were subsequently eroded and redeposited east of the fault to form sedimentary breccias (Unit C). Similar breccias were discovered by Larsen near Moona Vale Station (Neef, Larsen and Ritchie 1996, fig. 4). Sinistral transtension is consistent with the distribution of Unit A conglomerate near Hodges Overshot and north of the Great Wertago Mine, and sinistral drag is recognised in Emsian-Eifelian strata near Muckabunnya Waterhole.

Clasts derived from Ponto Beds in Unit C east of Gnalta Creek indicate some sediment derivation from the west. Palaeocurrent trends indicate dominant NE fluvial flow towards a depocentre near White Cliffs (i.e. within the Wonaminta Block).

KANIMBLAN OROGENY

Late Devonian strata form part of Menamurtee Dome, indicating that the dome was formed partly during the Kanimblan Orogeny (340 Ma, Powell 1984). The sinistral slickensteps and -lines along Muckabunnya Fault and the NW-trending fault that lies between the Gnalta Peak and Gnalta Creek faults may also have formed at this time.

CONCLUSIONS

1. During ?Emsian-Eifelian time a >3000 m thick sequence of fluvial strata was deposited in the area now represented by Copper Mine Range. Sediment transport was dominantly to the SE. The lower and upper parts of the sequence experienced an aeolian influence during deposition.

2. An orogeny, coeval with the Tabberabberan Orogeny of eastern Australia, deformed the ?Emsian-Eifelian sequence during ?late Eifelian - ?early Givetian time. Probable transtensional faulting at this time facilitated the intrusion of a kimberlitic sill near the base of the stratal succession.

3. The orogeny caused uplift to form a hilly terrain. Subsequently part of this terrain was buried by small boulders, cobbles and sand (Unit A).

4. In the Late Devonian, fluvial strata were deposited south of Copper Mine Range and there was sinistral activity on the Koonenberry and Muckabunnya Faults. Probable transtensional faulting occurred near Hodges Overshot and Great Wertago Mine, causing slivers of Mt Daubeny formation and Unit A to be preserved there.

ACKNOWLEDGEMENTS

B. Gall, N. Langford and L. Smith of Nuntherungie and Wertago Stations and Mt Daubeny Outstation respectively are thanked for accommodation and hospitality. B. Stevens provided a detailed draft geological map of the northernmost part of the study area adjacent to the Copper Mine Range (geology by B. Stevens and N. Raphael, Oct. 1984). K. Mills discussed aspects of Wonaminta petrology and N. Shepard and S. Davey, N.S.W. Department of Parks and Wildlife are thanked for co-operation. The referee is thanked for his valuable suggestions for improvement of the text. J. Vaughan assisted in the field and A. Fisk drew the drawings. The University of New South Wales provided financial assistance (faculty grants) and P. Adams (Fowlers Gap Station) was also supportive.

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A BIOGRAPHICAL REGISTER OF MEMBERS OF THE AUSTRALIAN PHILOSOPHICAL SOCIETY (1850-55) AND THE PHILOSOPHICAL SOCIETY OF NEW SOUTH WALES (1856-66). PART II.

A. A. DAY AND J. A. F. DAY

INTRODUCTION

Part I of this paper was published in the *Journal & Proceedings,* vol. 117: 119-127 (1984). Our objectives and methods for constructing the membership list were outlined in Part I. Briefly they were: to rectify the lack of a comprehensive list in any source then known to us, and to endeavour to augment a mere listing of names by adding such basic biographical details of the individuals as could be ascertained from resources mainly in Australia. Part I included 162 men (for they were all men), and the present part includes a further 166. The delay in presenting Part II for publication arose partly because about one quarter of the people were exceedingly difficult to identify. As sometimes happens, after we had exhausted all the then accessible sources of information, two events occurred which gave us new hope of progress. Firstly, a membership list turned up which from internal evidence could be dated precisely to September 1860. Secondly, a substantial improvement occurred in library collections of biographical resource materials. The publication in 1987 of the "Biographical Register" and in 1992 of the "Dictionary of Australian Artists" provided solutions to a few of our problems, but it was evident that the authors and editors of the latter magnificent work had also discovered some people's lives were impossibly obscure.

Additional Notes: (1) The spelling of MAC and MC names in the mid-1800s was erratic. We have adopted in the list the spelling most frequently used for an individual even though in the Philosophical Society's records the spelling may diverge from that. (2) A few of the men in the list below proved impossible to identify. We suspect that they were either country residents or transients, possibly visiting Sydney to assess commercial possibilities. (3) Three people whom we missed in our previous list are included below. (4) Under the protocols of the time, Governors Denison and Young, having agreed to act as Patron of the Philosophical Society of NSW, were in turn appointed President. The principal executive councillor was thus the Senior Vice-President (variously C. Nicholson, E. D. Thomson, W. B. Clarke). Governor FitzRoy, although he took an active part in the Australian Society, appears to have been content to act as Patron only, Thomson being President.

CORRECTIONS TO OUR PREVIOUS LIST

Beazley, Mr : *delete* Rev. Joseph; identified as Alexander Beazeley from PSN1860 list; *add* D. 1.12.1905, Weymouth, Eng.

Broadhurst : exhibited photographs 9.12.1859 (*not* 1850).

Dyer, Joseph : *add* also company secretary. D. 1916, Granville, Sydney.

Haydon, Henry : *delete* birth and death dates; *add* grocer.

Leathes: second name Stanger, *not* Stranger (error in Maiden).

ABBREVIATIONS AND REFERENCES

The three societies, Australian Philosophical, Philosophical and Royal are indicated by the symbols APS, PSN and RSN. Similarly the Linnean Society of NSW as LSN.

ADB Biog Reg: "A Biographical Register 1788-1939" compiled by H. J. Gibbney and A. G. Smith at the Australian Dictionary of Biography office, Canberra (2 vols, 1987).

AHAS : Australian Horticultural and Agricultural Society, Sydney.

AMG : Australasian Medical Gazette.

AMM : "Australian Men of Mark" E. Digby, ed. (Sydney, 1889).

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DAA : "Dictionary of Australian Artists" J.. Kerr, ed. (Melbourne, 1992).

JLCN : Journal of the Legislative Council of NSW.

Keating, J. D. : "Bells in Australia", (Melbourne, 1979).

Maiden, J. H. A contribution to a history of the Royal Society of New South Wales. *J. and Proc. Roy. Soc. NSW., 52* : 215-361 (1918). The principal printed source of information; a number of errors and omissions are listed in our Part I.

MJA : Medical Journal of Australia.

SMSA : Sydney Magazine of Science and Art. Only 2 volumes published.

Stokes, E. H. : "The Jubilee Book of the Sydney Hospital Clinical School" (Sydney, 1960).

Strahan, R. : "Rare and Curious Specimens" (Sydney: The Australian Museum, 1979).

Thomson, K., and Serle, G. : "Biographical Register of the Victorian Parliament 1859-1900" (Canberra, 1972).

Trans PSN 1862-5 : *Transactions of the Philosophical Society of New South Wales, 1862-65*, published 1866.

The work "The Mechanical Eye in Australia" by Con Tanre (pseudonym) referred to in our first part has been republished in extended form with A. Davies and M. Stanbury as authors (Oxford UP, Melbourne, 1985).

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EAGAR, N[icholas] H[enry]
PSN: in 1860 list. Accountant and retailer. Treasurer of the Sydney Mechanics' School of Arts, 1858-59. B. ca 1824, England; d. 24.8.1872, Ashfield, Sydney.

FAIRFAX, John
APS abt 1850; PSN: in 1860 list; RSN 1867-77. Newspaper proprietor. B. 25.1.1804, Warwick, Eng.; d. 16.6.1877, Sydney. See ADB 4: 148-149.

IRVING, Clark
PSN: in 1860 list, to 1865. Merchant, pastoralist and politician. B. 1808, Cumberland, Eng.; d. 13.1.1865, Brighton, Sussex, Eng. See ADB 4: 462.

LIDDINGTON, [John]
PSN visitor, exhibited coloured photographs 19.12.1859. Photographer and photographic colourist. B. ca 1823; d. 21.5.1873 buried at Inverell, NSW. See DAA, p. 472.

LIPPMAN, Julius
PSN 13.6.1856. Soap manufacturer, contractor, broker. B. ca 1821; d. 14.1.1873, Sydney.

LORD, Francis (Hon.)
APS and PSN implied. RSN 1867-1892. Storekeeper, pastoralist, politician. A son of Simeon Lord. B. Apr 1812, Sydney; d. 30.8.1892, Rydal, NSW. See ADB 2: 131; JRAHS 30: 191.

LOWE, Charles
APS 1850-?. Paper and exhibits re Argonauta, 2.9.1850 (abstract in SMH 5.9.1850).

Member of APS committee on fisheries. Probably the Charles Lowe, solicitor and secretary ofcompany, building society and Anglican church bodies in Sydney; insolvent 18.8.1855. 'Gentleman', of Sydney in 1864. Possibly went to S. Aust. abt 1866. Compare DAA, p. 480.

LUCAS, John

PSN 13.10.1858. Builder, company director and politician. One of the early explorers of the Jenolan Caves. B. 24.6.1818, Camperdown, Sydney; d. 1.8.1902, London, Eng. See ADB 5: 107.

MCARTHUR, Alexander

PSN 13.6.1856; continuing 1860. Shipping and general merchant; politician. B. 10.3.1814, Ireland; d. 1.8.1909, London, Eng. See ADB 5: 121.

MACARTHUR, George Fairfowl

PSN 8.7.1857. Anglican clergyman and schoolmaster. B. 19.1.1825; d. 16.6.1890. See ADB 5: 123.

MCCARTHY, W[illiam] G[odfrey]

PSN 16.11.1859; continuing 1860. Solicitor. B. ca 1810; d. 12.4.1873, Paddington, Sydney.

MACDONNELL, William

PSN 9.12.1857; continuing 1860. Exhibited microscopes, stereographs and photographs at PSN meetings in 1858, 1859, 1860. RSN 1867-1883. Jeweller and optician. B. ca 1813; d. 12.7.1883, Sydney.

MCEWAN, Dr [Donald McIntosh]

PSN 13.6.1856. Physician, Phillip St, Sydney; member, Board of Visitors to Lunatic Asylums. Member of AHAS 1856-58. Died 9.5.1859.

MCFARLAND, Andrew

PSN 17.8.1864. Possibly grazier in Hay district who died 14.7.1898.

MCGUIGAN, [?Alexander] J[ohn] B[ede]

PSN 13.6.1856 (not McGuyar, as in Maiden 1918: 264); continuing 1860. Hotelier, wine and spirit merchant in Bathurst. Active in local public affairs.

MCKAY, Charles (Dr)

PSN 8.10.1856 ; continuing 1860; microscopy committee. RSN 1876-1891. MD (St And), LRCS(Edin). Medical practitioner and author. B. ca 1822; d. 10.3.1898, Stanmore, Sydney. See AMG 17: 136.

MACKAY, Hugh

PSN 10.9.1856. Possibly the Hugh Mackay, gentleman, of Sydney, (and associate of J. W. Buckland, merchant) who died 1.9.1858.

MCLEAN, A[lexander] G[rant]

PSN 19.10.1859; continuing 1860. Survey draftsman and surveyor-general. The town of Maclean, NSW, is named after him. B. 1824, Scotland; d. 28.9.1862, Mulgoa, NSW.

MCLEAN, Hector

PSN 13.6.1856.

MACLEAY, William [John] ("William jnr") (Sir)

PSN 13.8.1856; continuing 1860. Politician, biologist and patron of science. Joint founder of the Entomological, and first president of the Linnean Societies of NSW; promoter of the "Chevert" expedition to New Guinea. Knighted 1889. B. 13.6.1820, Wick, Scotland; d. 7.12.1891, Elizabeth Bay, Sydney. See J&P 26: 5-6; ADB 5: 185-187.

MAITLAND, Edward

PSN 9.9.1857. Public servant and novelist. B. 27.10.1824, England; d. 2.10.1897, Kent, England. See ADB 5: 201.

MANN, Gother K[err]

PSN 13.6.1856; continuing 1860. Civil engineer and railway administrator. B. 1809, Ireland; d. 1.1.1899, Greenwich, Sydney. See NSW Railway & Tramway Magazine, 3: 746 (1920); DAA p. 509.

MANNING, William Montagu (Sir)

APS 1850 (at inaugural meeting). PSN transferred 1856; continuing 1860. Exhibit: 12.12.1861, photographs. RSN 1881-1895. Barrister and politician. B. 20.6.1811, Devon,

England; d. 27.2.1895, Edgecliff, Sydney. See ADB 5: 207-9.

MANSFIELD, S[amuel] [Worthington] (not H.)
PSN 13.6.1856. Manager of Sydney Benevolent Society; vice-president of the Sydney Mechanics' School of Arts committee. B. ca 1806; d. 19.3.1881.

MARTENS, Conrad
PSN 13.6.1856. Artist. B. 1801, London, England; d. 22.8.1878, North Sydney. See ADB 2: 212; DAA pp 513-6: E. Ellis, "Conrad Martens Life & Art" (Sydney, 1994).

MARTINDALE, Captain [Ben Hay]
PSN 12.8.1857; continuing 1860; council 1858. Engineer and public servant in NSW 1857-61. B. 1.10.1824, London, Eng. ; d. 26.5.1904, Surrey, England. See ADB 5: 220; DAA p. 518.

MAURICE, Solomon.
PSN 13.6.1856. Merchant, of Sydney.

MEREWETHER, Francis Lewis Shaw
APS 1850; council 1850. PSN ?date; continuing 1860. Public servant and Chancellor of Sydney University. B. 18.11.1811, Sussex, Eng.; d. 27.12.1899, Essex, England. See ADB 5: 241-2.

METHVEN, Capt. [Robert]
PSN visitor 17.10.1860; made valuable comments on compass deviation in iron ships in discussion following Rev. W. Scott's paper thereon. Ship's master for the P&O company. B. Cork, Ireland, 1816.

MILES, William A[ugustus]
APS 1850; secretary 1850. Commissioner of police, police magistrate and naturalist. B. 5.5.1798, Edinburgh, Scot.; d. 22.8.1851, Toowoomba, Moreton Bay Dist. of NSW [Qld]. See ADB 2: 228; DAA p. 535.

MILLER, F[rancis] B[owyer]
PSN 16.11.1859; council 1862, 1863, 1866. Paper, 18.7.1860, "On the detection of spurious gold". Exhibit, 17.12.1862, Minerals. RSN 1867-1869; corresp. member 1880-1887. FCSLond. Assayer, Sydney later Melbourne Mints; inventor of chlorine process of refining gold. B. ca 1829; d. 17.9.1887, Melbourne, Vic. See J&P 22: 6-7.

MILSON, James jnr.
PSN 13.7.1859; continuing 1860. RSN 1882-1903. Merchant. B. 25.11.1814, Sydney; d. 13.1.1903, Sydney. See ADB 2: 232-3.

MITCHELL, David S[cott]
PSN 13.6.1856; continuing in 1860. RSN 1867-1872. BA (Syd, 1856). Scholar; book-collector; founder of Mitchell Library, Sydney. B. 19.3.1836, Sydney; d. 24.7.1907, Sydney. See ADB 5: 260-1.

MITCHELL, James (Dr)
PSN 13.6.1856; continuing in 1860. RSN 1867 only. LRCS Edin. Medical practitioner; industrialist and politician; trustee of the Australian Museum 1853-69. B. 1792, Fife, Scotland; d. 1.2.1869, Sydney. See ADB 2: 235-8; Newcastle (NSW) History Monographs 1 & 6.

MITCHELL, Thomas Livingstone (Sir)
APS 1850 (committee 1850). Papers to APS: 17.6.1850, "On the external structure and undeveloped resources of the County of Cumberland"; 2.9.1850, "On the natural fruits and grasses of the Colony" (extended abstract in SMH, 8.9.1850); 3.12.1850, "The principle of the aboriginal boomerang applied to the propeller of steamships". Mr Charles Moore enquired at the PSN meeting on 5.10.1864 whether Mitchell's first paper specified above had been published, with negative result. Surveyor-general of NSW. B. 15.6.1792; d. 5.10.1855, Sydney. See ADB 2: 238; DAA pp. 541-2; JHL Cumpston, "Thomas Mitchell" (London, 1954); WC Foster, "Sir Thomas Livingstone Mitchell and his World 1792-1855" (Sydney, 1985).

MONTEFIORE, O[ctavius Levi]
PSN 8.7.1857. RSN 1878-1881. Exhibit to PSN, 19.12.1859, Six large imported photographs and an album of photographs taken by himself. Commission agent in Sydney, and for a time Consul for Belgium. B. (as "Levi") ca 1835 in West Indies; d. Sydney 4.7.1893. See DAA p. 545.

MOORE, Charles
APS 1850. PSN foundation member; council 1861-63 and 1866; microscopy committee. RSN 1867-1905; president 1880. Papers to PSN: 11.9.1861, "A brief notice of a few of the little known scrub timbers of the Colony". "5.10.1864, "On fibre-bearing plants indigenous to the Colony". 7.11.1866, "Remarks concerning a new species of Fagus". Botanist. Director of Botanic Gardens, Sydney. Trustee of Australian Museum. B. (as "Muir") 10.5.1820, Dundee, Scotland; d. 30.4.1905, Paddington, Sydney. See J&P 30: 18; ADB 5: 274.

MOREHEAD, R[obert] A[rchibald] A[lison]
APS 1850-55 (treasurer). PSN 1855-66 (treasurer 1855-58; council 1864, 1865). 17.12.1862, he exhibited copper ores. RSN 1867-1885. Businessman and mining promoter. B. ca 1814, Edinburgh, Scot.; d. 9.1.1885, Sydney. See ADB 2: 257-8; PLSN 10: 855.

MOREING, Henry
PSN 14.10.1857. Pastoralist, Braidwood, NSW. D. 15.5.1860, Sydney.

MORELL, G[ustavus] A[lphonse]
PSN 1.11.1865. RSN 1867-1888. Paper to PSN 6.9.1865: "On the defences of Port Jackson". Civil engineer. D. 4.8.1888, Sydney.

MORESBY, M[atthew] F[ortescue], RN.
PSN visitor 8.12.1858 and 19.12.1859; exhibited photographs. Naval secretary and paymaster; in Sydney with HMS 'Iris' 1856-60. B. ca 1828. See DAA pp. 546-7.

MORIARTY, E[dward] O[rpen]
PSN 13.6.1856; continuing 1860 (council 1860-63). Papers: 8.10.1856, "On the Parramatta waterworks" (published in SMSA 1: 76). 18.7.1860, "Memoranda referring to the destruction of the dam at Liverpool". 14.8.1861, "On the improvements in the navigation of the Hunter River". 9.10.1861, "A short description of the new works now being carried out for the improvement of Wollongong harbour". Exhibit: 18.7.1860, Plans for a steam dredge. MA(Dub), MInstCE. Civil engineer; public servant. B. 1825, Co. Kerry, Ireland; d. 18.9.1896, Southsea. Hants., England. See ADB 5: 291.

MORT, Henry (Hon)
PSN 10.6.1857; continuing 1860. Auctioneer; pastoralist; promoter of meat preserving for export; politician. Brother of T. S. Mort. B. 1818, Lancashire, Eng.; d. 6.9.1900, Woollahra, Sydney. See ADB 5: 301; Connolly, p. 240-1.

MORT, Thomas Sutcliffe
APS 1850. PSN continuing; in 1860 list. RSN 1867-69. Businessman with wide range of activities. See ADB 5: 299; J & L Lane, Hurstville Hist. Soc. (1983).

MOSES, Frederick
PSN visitor(?) 17.12.1862 and 6.7.1864; exhibits. Engineer.

MOSS, Israel
PSN ?date; continuing1860. Soap manufacturer in Sydney.

MOUNTCASTLE, B[enjamin Sutch]
PSN 13.6.1856. Hat manufacturer and vendor, Sydney. B. ca 1807; d. 7.4.1891, St Leonards, Sydney.

MULHOLLAND, T[homas]
PSN 13.6.1856. Possibly the grazier of Wagga Wagga district, who died 27.8.1870.

MURIEL, Robert
PSN, exhibitor of imported photographs 16.5.1862. Warehouseman and auctioneer.

MURNIN, M[ichael] E[gan]
PSN 7.6.1865-1866. RSN 1867-1894. Merchant; stock broker; magistrate; a director of Sydney Infirmary 1855-9. B. 1814, Ireland; d. 16.11.1894, Mittagong district, NSW. See ADB 5: 315.

MURRAY, T[erence] A[ubrey] (Hon.)
PSN 8.10.1862. RSN 1867-73. Pastoralist and politician. B. 1810, Ireland; d. 22.6.1873, Sydney. See ADB 2: 274; Trans RSN 7: 1; Connolly p. 243-4.

NAPER, Lieut. W[illiam] D[utton]
PSN 13.6.1856. Officer in the 11th Regiment, Sydney. In 1856-7 AdeC to Governor Sir William Denison (President of the Society).

NAPIER, Francis
PSN 14.10.1857; continuing in 1860. Engineer. Possibly the Francis Napier, member of Cadell expedition to Gulf of Carpentaria, 1867, who died 23.12.1875.

NATHAN, Charles
PSN 13.8.1856; continuing 1860. RSN 1868-71. Surgeon (pioneer in ether anaesthesia with J. Belisario). B. 1816, London; d. 20.9.1872, Sydney. See ADB 5: 327.

NEALDS, C[harles] J.
PSN 13.8.1856; continuing in 1860. Railway manager.

NICHOLSON, Charles (Sir)
APS 1850 (chaired founding meeting; subsequently vice-president). PSN 1855 to at least 1861 (vice-president 1855-7). MD (Edin 1833), DCL (Oxf), LLD (Camb). Baronet (1859). Physician, landowner, businessman, statesman, scholar, collector of Egyptian antiquities, and vice-provost and provost (later chancellor) of University of Sydney. Regarded as one of the most cultivated men in the colony in his time. He returned to England permanently in 1862. B. 23.11.1808, Cockermouth, England; d. 8.11.1903, London, Eng. See ADB 2: 283-5.

NORRIE, James [Smith]
PSN 8.7.1857; continuing in 1860. Pharmacist, photographer and inventor. Died 1883. See DAA, p. 586.

NORTON, James (senr.) (Hon.)
APS 1850 (gave the address at the founding meeting). PSN continuing in 1860. Solicitor and politician. B. 27.7.1795, England; d. 31.8.1862, Sydney. See ADB 2: 289.

O'BRIEN, B[artholomew] (Dr)
APS ?1850. PSN ?date; continuing 1860. RSN 1867-68. MD (Glas 1833). Medical practitioner. B. ca 1811; d. 18.1.1870, Concord, Sydney. See SMH 19.1.1870, p.4; Descent (Sydney) 14: 31-2, 1984.

ONSLOW, A[rthur Alexander Walton]
PSN, visitor 19.12.1859, exhibited stereographs from collodion negatives he took. Naval officer and politician. Trustee of Australian Museum 1872-80; member of "Chevert" expedition to New Guinea. B. 22.8.1833, India; d. 3.1.1882, Camden Park, NSW. See ADB 5: 369-370; DAA pp. 594-5.

OTTLEY, Osborn(e)
PSN 10.9.1856. Possibly lived on private income; active in various Sydney clubs and societies in the 1850s-60s. Possibly the Osbert Ottley buried Gore Hill Cemetery, 1900.

PELL, Morris Birkbeck
APS ?date. PSN from 1855 (council 1855-60, 1866; secretary 1861, 1863; microscopy committee). Papers: 11.7.1856, "Application of certain principles of political economy to the question of railways" (published SMH 14.7.1856, pp 2-3; discussion SMH 23.7.1856, p 3 and 22.8.1856, p 4. Also in SMSA 1: 124). 13.10.1858, "On the construction of dams" (published SMSA 2: 94). 7.12.1864, "On the distribution of profits in mutual life assurance societies" (published in Trans PSN, 1862-65, pp 267-308). RSN 1867-1875. BA (Camb 1849). Mathematician, actuary, businessman, barrister. Foundation professor of mathematics, University of Sydney. B. 31.3.1827, Illinois, USA; d. 7.5.1879, Glebe, Sydney. See J&P 13: 25-6: ADB 5: 428-9.

PENNINGTON, W[illiam] G[eorge]
PSN 13.6.1856. Paper, 11.7.1856, "Means of constructing railways, financially considered" (published SMH 14.7.1856, p 2; abstract in SMSA 1: 75). Solicitor, journalist and politician. D. 10.10.1875, Sydney. See Connolly pp 265-6.

PEPPERCORNE, Frederick S[eptimus]
PSN 1.6.1857. Paper: 12.8.1857, "On railways, with reference chiefly to the motive power" (published SMSA 2: 78). CE, LS.

Surveyor and civil engineer. B. ca 1814; d. 3.5.1882, Sydney.

PERCEVAL, Lieut-col. [John Maxwell], C. B.
PSN 8.12.1858; member of microscopy committee. Commanding officer of 12th Regiment and of H. M. Forces in New South Wales.

PERRY, C[harles] J[ames Clowes]
PSN: visitor, paper and exhibit: 19.9.1860, "On a dial to prevent collisions at sea" (published in Melbourne). Master mariner; politician (Victoria). B. ca 1816, London, Eng.; d. 20.8.1893, Williamstown, Vic. See Thomson & Serle 1972: 163.

PHILLIPS, Henry
PSN 13.6.1856; continuing 1860. RSN 1867-1884. Accountant. B. ca 1830; d. 30.3.1884, Surry Hills, Sydney.

PHILLIPS, Louis (sometimes Lewis)
PSN 3.7.1859; continuing 1860. With Moss, Moses and Co, merchants. Died 1873, Sydney.

PITTARD, Simon [Rood]
PSN 18.7.1860. MRCS(Lond). Curator of the Australian Museum, Sydney, 1860-61. B. 1821, Somerset, Eng.; d. 19.8.1861, Enfield, Sydney. See ADB Biog Reg 2: 181; SMH 21.8.1861 p. 9.

PLEWS, Henry [Taylor]
PSN 13.6.1856. Civil and mining engineer. Published pioneer work on NSW coalfields. Died 1885.

PLOMLEY, Jenner (Dr)
PSN 19.12.1859, exhibited numerous photographs including stereographs. Physician; of Hunter's Hill, Sydney. B. ca 1815; d. 1869, Balmain, Sydney.

PORTER, Henry John (according to Maiden), possibly Henry & John
PSN 11.7.1856. Commercial photographer(s), "Porter Brothers".

PRINCE, Henry
PSN 11.6.1862. RSN 1867-1881. Merchant, pastoralist and politician. B. ca 1818; d. 15.2.1882, Darlinghurst, Sydney. See Connolly pp 272-3.

PROESCHEL, [F]
PSN : visitor. 19.9.1860, Exhibited his map of Victoria and part of New South Wales. 17.10.1860, paper on Ozone. Geographer and map compiler; in Victoria from at least 1852; published an atlas of Australia in London, 1863.

RAE, John
PSN 9.9.1857. MA (Aberd 1832). Public servant, author and painter. B. 9.1.1813, Aberdeen, Scot.; d. 15.7.1900, Darlinghurst, Sydney. See DAA pp. 652-4.

RALPH, Dr [Thomas Shearman]
PSN 9.12.1857; continuing 1860. MRCS Eng, LSA Lond. Medical practitioner in New Zealand, briefly Sydney, then in Victoria. Founder of Microscopical Society of Victoria. B. ca 1812; d. 22.12.1891, Carlton, Vic. See AMG 11: 117.

RAMSAY, Edward Pierson
PSN 7.6.1865. Papers: 5.7.1865, "On the oology of Australia" with exhibits (published in Trans PSN 1862-5, pp 309-329); 4.7.1866, "On the ornithology of Lake George". RSN 1867-1916. LLD (St And 1866). CMZSLond, FLS, FRSE, FRGS, MRIA. Ornithologist and general zoologist; curator of Australian Museum, Sydney, (1874)1876-1893. B. 3.12.1842, Ashfield, Sydney; d. 16.12.1916, Croydon Park, Sydney. See ADB 6: 3-4; Strahan 1979: 37-46.

RANDLE (sometimes RANDELL, RANDAL), William
PSN 13.6.1856. Railway contractor in England and Australia. B. 1826; d. 17.11.1884, London, Eng. See ADB Biog Reg 2: 200.

RANKEN, Thomas
PSN 13.5.1856. Possibly the Thomas Ranken born 20.10.1830, who died Marulan 16.6.1860.

RATTRAY, Dr [Alexander], MD.
PSN ?correspondent only: Paper, 8.11.1865, on Cape York peninsula. Naval surgeon, traveller and writer.

RAYNER, F[rederic] M[athew]
PSN: visitor. 14.7.1858: Exhibited live marsupials from Western Australia. Naval surgeon, HMS "Herald".

ROBERTS, Alfred (Dr) (Sir)
PSN 13.6.1856 (councillor 1858-61, secretary 1862; microscopy committee). Papers: 14.10.1857, "On the poison apparatus of venomous snakes" (published in SMSA 1: 130 and 2: 50). 14.7.1858, "On the poison apparatus of venomous snakes, part 2, with a description of some of the species found in this colony" (published in SMSA 2: 58). 13.7.1859, "On a new mode of using Canada balsam and other adhesive fluids in mounting microscopic objects". 14.8.1861, "On a new species of foraminiferous shell from Ovalau, Feegee". MRCS Eng, LSA Lond. Knighted 1883. Surgeon, hospital founder and naturalist. B. 1823, London, Eng.; d. 19.12.1898, Wentworth Falls, NSW. See J&P 33: 2; ADB 6: 34-5.

ROBERTS, John
PSN 13.6.1856; continuing in 1860. RSN 1867-1888. Watchmaker and jeweller; partner in Flavelle Bros. & Co., Sydney.

ROBERTS, William
PSN 13.6.1856; continuing 1860. Probably the solicitor and politician (MLA for Goulburn 1859-60) who was b. ca 1821; d. 1.7.1900. See Connolly p 283.

ROBERTSON, James (Dr)
PSN 13.6.1856; continuing 1860. MB (Lond), MD (St And), FRCS. Medical practitioner; founder of Australian Medical Association, 1859. B. ca 1822; d. 1862, Parramatta, NSW. See MJA 1951(1): 533.

ROBERTSON, T. W.
PSN membership list, 1860, of East Maitland. Almost certainly an error for J. W. Robinson, q.v.

ROBEY, James
PSN 11.8.1858. Sugar manufacturer; brother of R. M. Robey. B. ca 1807; d. 1872, Sydney.

ROBIE, Thomas Battaby
PSN 13.6.1856.

ROBINSON, J[ames] W[ilkie]
PSN 10.9.1856; continuing 1860, of East Maitland (listed as Robertson). School teacher; arrived NSW 1837; returned to Scotland in 1860s. B. Glasgow; d. 1875, E. Maitland.

RODD, J[ohn] S[avery] (not J. J. as in Maiden)
PSN 10.9.1856; continuing 1860. Assistant surveyor; pastoralist at Bathurst, Capertee and South Creek, NSW. B. ca 1807, Devon, England; d. 26.1.1870, Potts Point, Sydney.

ROLLESTON, Christopher
PSN 12.11.1856 (treasurer 1859-63). Papers: 10.12.1856, "The science of statistics" (SMSA 1: 254-8). 10.6.1857, "On the sanitary condition of Sydney" (SMSA 1: 37-41). 11.8.1858, "On the mortality of Sydney" (SMSA 2: 81). 3.7.1859, "On the means of deodorizing and utilizing the sewage of towns" (SMSA 2: 235-240). 19.6.1861, "On the census of 1861". 12.12.1866, "On the condition and resources of the Colony". RSN 1867-88. Statistician, registrar-general, auditor-general, non-resident pastoralist and company director. B. 27.7.1817, Nottinghamshire, Eng.; d. 9.4.1888, Milson's Point, Sydney. See J&P 22: 3; ADB 6: 55-56.

ROSS, [Joseph] Grafton
PSN 6.12.1865. RSN 1867-97. Sugar company manager. B. 9.6.1834, Kidderminster, Eng.; d. 4.7.1906, Bournemouth, Eng. See ADB 6: 62.

ROTHERY, Frederick [John]
PSN 10.9.1856. Pastoralist and mining promoter. B. 1804, Hampshire, Eng.; d. 19.3.1860, Double Bay, Sydney. See JRAHS 17: 274 (date of death incorrect).

ROWLEY, George
PSN 19.6.1861. Solicitor. B. ca 1822; d. 10.10.1866, Newtown, Sydney.

RUSSELL, George
PSN 13.5.1857. Probably the George

Russell, engineer, who at this time was a partner of P. N. Russell & Co, engineers.

RUSSELL, Henry Chamberlain
PSN 7.9.1864. RSN 1867-1907. Astronomer and meteorologist. Joint founder of the Australasian Association for the Advancement of Science. B. 17.3.1836, West Maitland, NSW; d. 22.2.1907, Sydney Observatory. See J&P 41: 23; ADB 6: 74-5; R. Bhathal 1991, J&P 124: 1-21.

SAGE, Alex[ander]
PSN 10.9.1856. Stock and station agent in Parramatta, and Sydney in early 1860s.

SALOMONS, Julian E[manuel] (Sir)
PSN 13.6.1856. Barrister and politician. B. 4.11.1835, Birmingham, Eng.; d. 6.4.1909, Woollahra, Sydney. See ADB 6: 81-83; Connolly p. 294-5; Bennett, 1977: 26-29.

SALTER, John Leslie (Dr)
PSN 10.12.1856; continuing 1860. Medical practitioner. B. ca 1804; d. 1869, Berrima, NSW.

SAMUEL, Saul
PSN 13.6.1856; continuing 1860. RSN 1876-81. Merchant and politician. B. 2.11.1820, London, Eng.; d. 29.8.1900, London, Eng. See ADB 6: 84-5; Connolly p. 295-6.

SAMUELS, B. S.
PSN exhibitor, 17.12. 1862, of copper ores and ingots from Ophir and Cadiangullong, NSW.

SCOTT, Captain D[avid Charles Frederick]
PSN 3.6.1856; continuing 1860. Police magistrate, Sydney. B. 1804, Bombay, India; d. 16.5.1881, Paddington, Sydney. See ADB 2: 428; DAA pp. 703-4.

SCOTT, J[ames] H[oughton] L[angston]
PSN 11.5.1859, continuing 1860. Gold commissioner, police magistrate, NSW. D. 1878.

SCOTT, Captain [Lawrence Hartshorne]
PSN 10.6.1857, continuing 1860. Officer, 11th Regiment; AdeC to Governor Denison (President of the Society). D. 1879.

SCOTT, William (Rev.)
PSN 10.9.1856 (council 1857-61). Papers: 14.10.1857, "On the meteorology of New South Wales" (SMSA 2:128). 11.8.1858, "On the meteorology of New South Wales, No. 2" (not published). 10.11.1858, "On the plurality of worlds" (SMSA 2: 131). 10.8.1859, "On the observatories of the southern hemisphere". 19.10.1859, "On the Sydney Observatory", with exhibits. 20.6.1860, "On the Sydney Observatory". 17.10.1860, "On compass deviation in iron ships". 17.7.1861, "On the Sydney Observtory and Tebbutt's comet". RSN 1867-1917. BA (Camb 1848), MA (Camb 1851). Anglican clergyman, NSW Government astronomer (1856-62), school headmaster (1863-5), college warden (1865-78), minister in Goulburn diocese (1879-88). B. 8.10.1825, Devonshire, Eng.; d. 29.3.1917, Chatswood, Sydney. See J&P 51: 6; ADB 6:97.

SEVERN, Henry A[ugustus]
PSN 13.7.1859; member of microscopy committee. Clerk (1853-61), later assistant assayer (1861-64), in Sydney mint; also a painter and photographer. Paper: 8.6.1859, "On the construction of specula for reflecting telescopes". Exhibit: 19.12.1860, family etchings and watercolours. Noted in DAA, p. 715.

SEYMOUR, Commodore [Frederick Beauchamp Paget]
PSN (no date of election). Commodore of the Australia Station, Royal Navy. Paper: 13.8.1862, "On the performance of the ASN Co's steamer 'Diamantina' between Sydney and Brisbane and return to Sydney". B. 1821.

SHADLER, A[dolph]
PSN visitor 17.7.1861, announced his invention of an oven thermometer. Baker, Sydney. D. 19.5.1901, Germany.

SHANKS, Archibald (Dr)
APS 1850; committee 1850. Principal army medical officer. MD (Edin 1813). D. 28.8.1853, Hobart. See Peterkin & Johnston 1968, 1: 247.

SMALLEY, George Robarts

PSN 7.9.1864 (council 1865, secretary 1866). Papers: 2.8.1865, "On the theory of Encke's comet" (Trans 1862-5, pp. 330-8). 11.10.1865, "On certain possible relations between geological changes and astronomical observations" (Trans 1862-5, pp. 338-346). 6.12.1865, "On the present state of astronomical, magnetical and meteorological science, and the practical bearings of those subjects" (Trans 1862-5, pp 347-356). 1.8.1866, "Preliminary remarks on the magnetical survey of New South Wales" with exhibits. Played a major role in conversion of PSN into RSN, 1865-6. RSN 1867-70. BA (Camb 1845). Astronomer and mathematician; initiated magnetic and tidal studies. B. April 1822, Banbury, Oxfordshire, Eng.; d. 11.7.1870, Sydney. See Trans RSN 4: 47-48, and 5: 1-2; ADB 6: 136.

SMITH, James

PSN 14.10.1857; continuing in 1860. Surgeon. Apparently in Liverpool, NSW, 1857-74.

SMITH, John (Hon)

APS 1852. PSN foundation member (secretary, 1855-60, 1862; council 1864-66; microscopy committee). Papers: 13.8.1856, "On the action of Sydney water upon lead" (SMSA 1: 104-6). 16.11.1859, "On the separation of gold from mundic quartz". 15.8.1860, "On the quartz reefs of lower Adelong" with exhibits (JLCN 1860: 204-5) [Title recorded as "upper Adelong" by Maiden]. 11.11.1863, On ancient flint implements found near Abbeville" [omitted by Maiden]. 11.8.1864, "On the probable reasons that led Fahrenheit to the adoption of his peculiar thermometric scale". Played a substantial role in conversion of PSN into RSN, 1865-6. RSN 1867-1885. MA, MD, HonLLD (Aberd 1843, 1844, 1876 resp). CMG (1878). Professor of chemistry and experimental physics, also photographer, University of Sydney; company director and politician; tireless worker for philanthropic causes. B. 12.12.1821, Peterculter, Aberdeenshire, Scot.; d. 12.10.1885, Sydney. See J&P 20: 1-6; ADB 6: 148-150; R. MacLeod (ed.), "University and Community in Nineteenth Century Sydney Professor John Smith 1821-1885 (Sydney, 1988).

SPARKES, J[ohn] S[ay] ("Captain")

PSN 11.7.1856. Shipping company representative in Sydney; deputy chmn of Fitzroy Iron Co., 1855.

SPYER, [? Lawrence Joseph]

PSN: on 17. 12. 1862 Spyer & Co. exhibited specimens of DeLaRue's new parchment paper for chemical and documentary purposes. Presumably this was Lawrence Joseph Spyer, who conducted in Sydney the firm of L & S Spyer & Co., merchants and commission agents, with head office in London. The Sydney firm was insolvent by 1866.

SQUIRE,

PSN 13.7.1859; in 1860 list 'of Wid Bay' [Queensland].

STACK, William (Rev.)

PSN 5.7.1865. Anglican clergyman, Balmain, Sydney. B. ca 1810, Ireland; d. 13.6.1871, near Willow Tree, NSW. See ADB Biog Reg 2: 276; Heaton p. 188.

STAFFORD, Charles

PSN 12.11.1856; continuing 1860. Solicitor. B. ca 1824; d. 13.11.1865, Double Bay Sydney.

STAFFORD, John

PSN 12.8.1857; continuing 1860. Architect. D. 30.12.1887, Sydney.

STANLEY, G[eorge] H[eape] [B.] (Rev.)

PSN 13.6.1856. Unitarian clergyman and school teacher. BA (Lond); MA (Syd 1861); LLD (Syd 1866). B. ca 1817; d. 12.3.1891, Coogee, Sydney.

STEPHEN, Alfred (Sir)

APS 1850. PSN continuing in 1860. Chief justice and politician. B. 20.8.1802, West Indies; d. 15.10.1894, Sydney. See ADB 6: 180-187; Bennett, 1977: 18-21.

STEPHENS, William John

PSN 9.9.1857; continuing 1860; (council 1862-63, secretary 1864-66). RSN 1867-90.

Headmaster of Sydney Grammar School 1856-66; Professor of natural history, later geology, University of Sydney 1882-90; trustee of the Australian Museum 1862-73, 1879, 1883-90. B. 16.7.1829, Westmoreland, Eng.; d. 22.11.1890, Darlinghurst, Sydney. See J&P 25: 6; PLSN 5ns: 900-2; ADB 6: 197.

STUTCHBURY, Samuel
APS 1850 (council 1850). FGS. Naturalist and geological and mineralogical surveyor. B. 15.1.1798, London, Eng.; d. 12.2. 1859, Bristol, Eng. See ADB 6: 216-7; DAA p. 772; DF Branagan, Bull. Roy. Soc. N. Z., 21: 7-15 (1984) and "Science in a Sea of Commerce" (Sydney, 1996).

TAYLOR, John.
PSN 13.6.1856, of Barrack Street, Sydney; in 1860 list, of Margaret Street, Sydney. Possibly the engineer and contractor, see ADB.BR 2:295.

TEBBUTT, John jnr
PSN 14.8.1861. Papers: 13.8.1862, "On the desirability of a systematic search for, and observation of, variable stars in the southern hemisphere" (Trans 1862-5, pp 126-139). 8.10.1862, "On the comet of September, 1862, No. 1" (Trans 1862-5, pp 140-146). 12.11.1862, "On the comet of August and September 1862" [2nd paper] (Trans 1862-5, pp 146-153). 7.9.1864, "On Australian storms" (Trans 1862-5, pp 153-164, with commentary by W. B. Clarke, pp. 165-177). RSN 1867-1916. FRAS 1873. Farmer; private astronomer of international fame. B. 25.5.1834, Windsor, NSW; d. 29.11. 1916, Windsor, NSW. See J&P 51: 6; ADB 6: 251; R. Bhathal, "Australian Astronomer John Tebbutt". (Kenthurst, NSW, 1993).

TERRY, F[rederick Casemero]
PSN 13.6.1856. Artist and engraver. B. 1825, Great Marlow, Eng.; d. 10.8.1869, Sydney. See ADB 6: 256-7; DAA pp.784-786.

TERRY, Samuel Henry
PSN 8.10.1856; continuing 1860. Land owner and politician. B. 9.4.1833, Pitt Town, NSW; d. 21.9.1887, Ashfield, Sydney. See Connolly, pp 329-330; ADB 6: 258-9.

THERRY, Roger (Sir)
APS 1850. Judge (in NSW 1829-1859). B. 1800, Cork, Ire.; d. May 1874, Bath, Eng. See ADB 2: 512-4.

THOMAS, James Henry
PSN 13.6.1856, of Cockatoo Island. Paper 13.8.1856: "On the iron-making resources of N. S. Wales", printed in SMSA 1: 101. Engineer (C.E.) in NSW govt. service, initially railways, later roads.

THOMPSON, Henry Alderson
PSN, date of election unclear. RSN 1870-1885. Papers: 11.8.1858, "On the Clunes mine, Victoria"; "Outline of a plan for the formation and working of a mining company to open out the quartz fields of N. S. Wales". 8.6.1859, "Specification of twelve-head stamping mill for crushing quartz" (SMSA 2: 231-235). 1871, "Notes on the auriferous slate and granite veins of New South Wales". Mining engineer. B. ca 1820; d. 4.1.1886, Launceston Tas.

THOMPSON, John
APS, ?date. PSN, foundation member; committee 1855-57. Papers: 10.9.1856, "Electric telegraphs and railways between Sydney and London not impossible". 10.2.1856, "On the necessity for further exploration of the interior of the Australian continent" (SMSA 1: 232 and SMH 13.12.1856 p. 5). Deputy surveyor-general for NSW, 1854-61. B. 1800, England; d. 9.5.1861, Sydney.

THOMPSON, J[ohn] Malbon
PSN 13.6.1856. Solicitor and politician. B. 24.12.1830, Sydney; d. 30.5.1908, Sydney. See ADB 6: 265-6.

THOMPSON, Richard.
PSN 13.6.1856., of Macquarie Street, Sydney. Possibly the journalist and editor of that name.

THOMPSON, R[ichard] Windeyer
PSN 13.6.1856. Solicitor, in Sydney to 1865 then West Maitland. MLA for West

Maitland, 1885-91. B. 1831, son of John Thompson, Deputy S-G, above; d. 19.11.1906, West Maitland.

THOMSON, Edward Deas (Sir)
APS 1850 (founding President). PSN 1855-66 (founding joint vice-president -1866). Papers: 13.6.1856, "On steam communication with England: 1. On the application of auxiliary steam power to passenger ships in the Australian trade; 2. Proposal for combining a system of postal communication with immigration" (SMH 14.6.1856, p.3). RSN 1867-72. Skilled and effective senior administrator in NSW colonial government prior to responsible government. C.B. B. 1.6.1800, Edinburgh, Scot.; d. 16.7.1879, Sydney. See ADB 2: 523-7; SG Foster, "Colonial Improver" (Melbourne, 1978).

THOMSON, Robert
PSN 13.6.1856; continuing 1860. Actuary. Brother of Lord Kelvin. B. 25.2.1829, Belfast, Ire.; d. 5.9.1905, Prahran, Vic. See ADB 6: 269-270.

TORNAGHI, A[ngelo]
PSN 19.6.1861; RSN 1867-69. At PSN meeting 19.10.1859 Rev. W. Scott exhibited an astronomical azimuth scale made by him. At PSN microscopy committee meeting 5.9.1860 Sir Wm. Denison exhibited a set of scales for weighing microscopic objects, made by him. Watch, clock and mathematical instrument maker & inventor; mayor of Hunter's Hill. B. 1831, Milan, Italy; d. 1906, Sydney. See AMM 2: 226-230 (port); Keating p. 57.

TRICKETT, Joseph
PSN 13.6.1856; microscopy committee; continuing 1860. Engineer, Sydney Branch Mint, 1854-73. D. 3.1.1878, London, Eng. See ADB 6: 302.

TUCKER, James C.
PSN 13.6.1856; continuing 1860. Wine merchant, Sydney.

TURNER, George E[dward Weaver] (Rev)
APS 1850 (council 1850). PSN 1855; continuing 1860 (council 1856). Anglican clergyman; botanist. Trustee of the Australian Museum 1847-69. B. ca 1811; d. 10.1.1869, Ryde, Sydney. See SMH 12.1.1869 p.4.

UHR, William C.
PSN 9.9.1857. Clerk in Sheriff's Dept., Sydney. D. 1896, Sydney.

VIGORS, Lieut. [Phillip Doyne]
PSN 13.6.1856. Paper: 10.6.1857, "On pavements and street surfaces" (SMSA 2: 11-15, 26-31). Officer, 11th Regiment, Sydney; AdeC to Governor Denison, President of the Society, 1855-56. B. 23.12.1825, Ireland; d. 30.12.1903, county Carlow, Ireland. See Burke's Irish Family Records, 1976: 1169.

WADE, W[illiam] Burton
PSN 13.6.1856; continuing in 1860. Civil and railways engineer. B. ca 1833; d. 12.7.1886, Ashfield. See SMH 13.7.1886 p. 7.

WALKER, George (Dr)
PSN 14.10.1857; continuing 1860. Medical practitioner. B. ca 1831, England; d. 18.9.1870, Sydney. See NSW Med Gaz 1: 58.

WALKER, William
PSN 5.10.1864. RSN 1868-71. Solicitor and politician. B. 26.2.1828, Glasgow, Scot.; d. 12.6.1908, Windsor, NSW. See ADB 6: 344.

WALL, [William] Sheridan
PSN 13.6.1856. Curator, Australian Museum, Sydney, 1840-1858; natural history artist. B. 1815, Dublin, Ireland; d. 1876, Sydney. See ADB Biog Reg 2: 325; DAA p. 831.

WANT, Randolph John
APS 1850 (council 1850; committee on fish). PSN 1856-69? (council 1856-7, 1859-61). Solicitor, company director and politician. Trustee of Australian Museum 1856-7, 1859-69. B. 1811, London, Eng.; d. 28.6.1869, Sydney. See ADB 6: 349-350; DAA p. 836.

WANT, R[andolph] C[harles]
PSN 13.6.1856; continuing 1860. Solicitor. BA (Syd 1858); MA (Syd 1861). D. 20.2.1895, Theole, France.

WARD, Edward Wolstenholme (Capt.)
PSN 1855-64? (joint secretary 1855-61, 63; member microscopy committee). Papers: 12.5.1858, "On the strength and elasticity of woods of New South Wales and New Zealand" (SMSA 1: 258-263). 10.8.1859, "Analyses of Warriora coal and Bellambi coke, together with the results of rough experiments on the heating power of colonial coal". 7.12.1864, "On the prospects of the civil service of New South Wales under the Superannuation Act of 1864" (Trans 1862-5, pp 215-222). Exhibit: 7.9.1859, photomicrographs of wood taken by himself. RSN: Corresponding member 1880-90. KCMG 1879. Captain of Royal Engineers; Deputy Master of Royal Mint and head of Sydney Branch Mint, 1854-66; head of Melbourne Branch Mint 1869-76. See J&P 24: 10-11; ADB 6: 352-3; DAA p. 836.

WATT, Charles
PSN 13.7.1859 (council 1862; microscopy committee). RSN 1867-99. Analytical chemist; soap manufacturer and oil shale distiller; government analyst 1880-5. D. 19.7.1899, Parramatta. See J&P 34: 2-3.

WAUGH, [James William]
PSN 10.6.1857. Bookseller and publisher. B. (as James only) 16.12.1819, Edinburgh, Scot.; d. 22.10.1867, Kiama, NSW. See DAA p. 843.

WAYMOUTH, H[enry]
PSN 13.8.1856. Private school master in Sydney 1854-56. Possibly related to the Waymouth family of Devon, England, prominent in education and the church.

WEAVER, William
PSN 13.6.1856; continuing 1860. Architect and civil engineer.

WEST, John (Rev.)
PSN 13.6.1856. Congregational clergyman, newspaper editor and author. B. 1808, England; d. 11.12.1873, Woollahra, Sydney. See ADB 2: 590-2.

WILLIAMS, J. P. [? John only]
PSN 1862-66. RSN 1869-77, of New Pitt St., Sydney. Fits John Williams, J.P., cooper, of that address.

WILLIAMS, W[illiam] J (Dr)
PSN 8.7.1857; continuing 1860 (council 1862; microscopy committee). Paper: 10.8.1859, "On the adulteration of milk in Sydney" (report by the members of the Microscopy Committee). MRCS Eng 1847; LSA 1848; MD (St And 1848). Medical practitioner. B. ca 1825, Liverpool, Eng.; d. 27.9.1873, Sydney. See NSW Med Gaz 4: 26-27, 32.

WILLIAMSON, James
PSN 13.8.1856. Pastoralist and politician. B. 1811, Edinburgh, Scot.; d. 8.3.1881, Burwood, Sydney. See Connolly pp. 361-2.

WILLIS, Joseph Scaife
PSN 10.11.1858. Merchant. B. 10.5.1808. Scotland; d. 15.7.1897, Mosman, Sydney. See ADB 6: 408.

WINGATE, Major [Thomas]
PSN 12.5.1858; member of microscopy committee; continuing 1860. Army officer and artist. B. ca 1807; d. 1869, Potts Point, Sydney. See DAA p. 870.

WINNINGTON, J[ohn T.]
PSN 6.12.1865. Ensign, 12th Regiment, Sydney.

WISE, Edward (Hon.)
PSN 13.6.1856; continuing 1860. Barrister, politician and judge. B. 13.8.1818, Isle of Wight, Eng.; d. 28.9.1865, Sydney. See ADB 6: 427-8.

WOOLLEY, Rev. John
APS, ?1852; PSN, continuing from APS; PSN council 1855-59; continuing 1860. Clergyman, teacher, professor of classics and principal, University of Sydney. DCL (Oxf 1844). B. 28.2.1816, Hampshire, Eng.; d. 11.1.1866, Atlantic Ocean off Bay of Biscay. See ADB 6: 435-437; KJ Cable 1968, "John Woolley. ", Arts 5: 47-64.

WOOLLEY, Thomas
PSN 10.9.1856. Ironmonger, Sydney. D. 18.2.1858.

WOORE, Thomas
PSN 13.8.1856. Papers: 10.12.1856, "On a new grate for burning wood" (SMSA 2: 32-35). 11.9.1861, "On a new mode of constructing timber bridges" and "On a new method of giving support to railway bars". CE. Naval officer, engineer and pastoralist. B. 29.1.1804, Ireland; d. 21.6.1878, Double Bay, Sydney. See ADB 6: 439; DAA pp. 882-3.

APPENDIX 1. FOUNDATION MEMBERS OF THE PHILOSOPHICAL SOCIETY OF NSW

Professor John Smith, reviewing the inauguration of the Philosophical Society of NSW in 1855-6, states: "It seems that twenty-two members passed over from the [Australian Philosophical] Society to the new" (1881,*J&P* vol 15: 3). From the foregoing it is possible to formulate a reasonably accurate list containing twenty-eight names. The discrepancy between Smith's figure and ours could have various origins which, in the absence of detailed membership records are not worth pursuing:-

A'Beckett, Dr A. M.

Allen, George

Allen, Wigram

Barney, Colonel George

Bland, Dr William

Cape, W. T.

Clarke, Rev. W. B.

Douglass, Dr H. G. (Hon. Sec.)

Fairfax, J.

Holden, G. K.

Holroyd, A. T.

WRIGHT, Adam
PSN 13.6.1856. Possibly the Hunter River railway contractor.

WYATT, Rev. A[rthur] H[aute]
PSN 6.12.1865; RSN 1867. Anglican clergyman (deacon), Berrima and Sutton Forest, NSW. B. 1830; d. 1871.

YOUNG, His Excellency Sir John
PSN 15.5.1861; president 1861-67; RSN 1867, president 1867. Governor of New South Wales, 1861-67. B. 1807, Bombay, India; d. (as Baron Lisgar, 1870) 6.10.1876, Ireland. See ADB 6: 455-457.

Lord, F.

Manning, W. M.

Moore, C.

Merewether, F. L. S.

Morehead, R. A. . (Hon. Treas.)

Mort, T. S.

Nicholson, C.

Norton, J. senr.

O'Brien, Dr B.

Pell, Prof. M. B.

Thompson, J.

Smith, Prof. J.

Stephen, A.

Woolley, Prof. J.

Thomson, E. Deas (absent overseas)

Turner, Rev. G. E. W.

Want, R. J.

APPENDIX 2. OCCUPATIONS AND INTERESTS OF THE SOCIETY MEMBERS

It is interesting to gain some impression of the types of occupation represented by the membership, recognising that in the 1850s and

1860s men with specialised qualifications in science, technology or engineering were rare in the colony. Also, the boundaries between technical occupations were not so sharply defined as they are now. Those men who joined appear, from the fact that most did not have technical backgrounds, to have had at least a superficial interest in such matters. There can be no doubt, at least in the mind of a cynical modern oberver, that some who joined did so for the social cachet attached to a Society headed by the Governor who was an active participant, not merely a decorative Patron. It is interesting that a sizeable number of men involved in primary production joined when there was available the specialised forum provided by the Australian Horticultural and Agricultural Society. Again, it would be nice to think that some of the politicians joined in order to appreciate better some of the public policy issues affected by scientific considerations; this was certainly true in relation to railway development, for example. Medicos appear to have joined partly for the natural history interest, partly in connection with the serious public health issues which needed to be publicised and discussed. Certainly the small number of real scientists must have felt encouraged by a constructive atmosphere much different from today's politicised and financially rationalist environment.

The statistics given in the table give unit weight to each of the members' known occupations and serious interests. To have attempted fractional weighting we felt would have involved too much guesswork. The grand total therefore substantially exceeds the number of members (328).

OCCUPATION OR INTEREST	
Politician	51
Engineer, builder, contractor, surveyor, architect, draftsman	45
Legal	41
Medical practitioner, dentist	39
Merchant, retailer, auctioneer	36
Farmer, pastoralist, settler, vigneron	33
Public servant	32
Company director, secretary, manager	20
Clergyman	19
Navy and army	18
Author, journalist, printer, publisher, bookseller	17
Artist, engraver, photographer	17
Manufacturer	15
Schoolteacher	12
Biologist, botanist, naturalist, museum curator	12
Mine engineer, promoter, geologist, geographer	12
Assayer, chemist, pharmacist	10
Accountant, banker	8
Academic, scholar, book collector	8
Gentleman, financier	6
Astronomer, meteorologist	6
Actuary, mathematician, statistician	5
Shipping manager, captain	4
Inventor	1
TOTAL	457

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TRACE ELEMENTS IN COAL SCIENCE

D.J. Swaine

ABSTRACT. Trace elements are relevant to several aspects of coal science. Five topics are dealt with in detail, namely, the occurrence of trace elements, boron as an indicator of marine influence, boiler deposits, fluorine in coal, and the deposition of trace elements from the atmosphere. There is an increasing interest in the fate of trace elements from the combustion of coal for power production, especially environmental aspects of trace elements from the atmosphere and from ash disposal areas. Several suggestions for future work are outlined.

INTRODUCTION

It is a pleasure to thank the Royal Society of New South Wales for the invitation to give the Liversidge Research Lecture and the Sydney University Chemical Society for arranging the joint meeting for the presentation. Professor Liversidge directed in his Will that the lecture should cover the results of the lecturer's recent research. Some of Liversidge's early work dealt with coal, for example, gold in the coal measures and coal from the Wallerawang area. Hence, my topic is relevant. In 1872 Liversidge left England to fill the position of Reader in Geology and Demonstrator in Practical Chemistry at The University of Sydney. In 1882 he was appointed Professor of Chemistry and Mineralogy. He was a pioneer in setting up courses in chemistry and influenced greatly the progress of science, in particular, encouraging women to study science. Relevant information on Liversidge's activities at The University of Sydney and in The Royal Society of New South Wales is given by LeFevre (1968) and by Branagan and Holland (1985). Liversidge was primarily a chemical mineralogist whom I regard as Australia's first geochemist.

There are several aspects of trace elements in coal science that are noteworthy, for example,
During coalification
Occurrence (speciation), especially with mineral matter
Effects of marine influence
Changes during mining
Use for seam correlation
During beneficiation (coal cleaning)
Boiler deposits
Analytical methodology, especially at trace and ultratrace levels
Redistribution during combustion for power production
Association with flyash
In stack emissions from power stations
In deposition from the atmosphere around power stations
Rehabilitation after mining
Possible health effects
As a source of metals and non-metals.
Five of the above topics which are part of my research will be discussed.

Nowadays the stress is on environmental aspects of coal usage. This gives trace elements a major role which is generating a mass of applied and basic research, notably in the USA (Swaine and Goodarzi, 1995).

OCCURRENCE OF TRACE ELEMENTS

As well as knowing the concentrations of trace elements in coal, it is important to ascertain how they occur (speciation). Much work has been and is being done on speciation which is difficult because so many elements are present in different forms and at parts per million (ppm) and sub-parts per million levels. The total content of a trace element in coal is made up of two main components, namely, organic and mineral, each having several possible forms. For example, the organic may be intrinsic (derived from the early

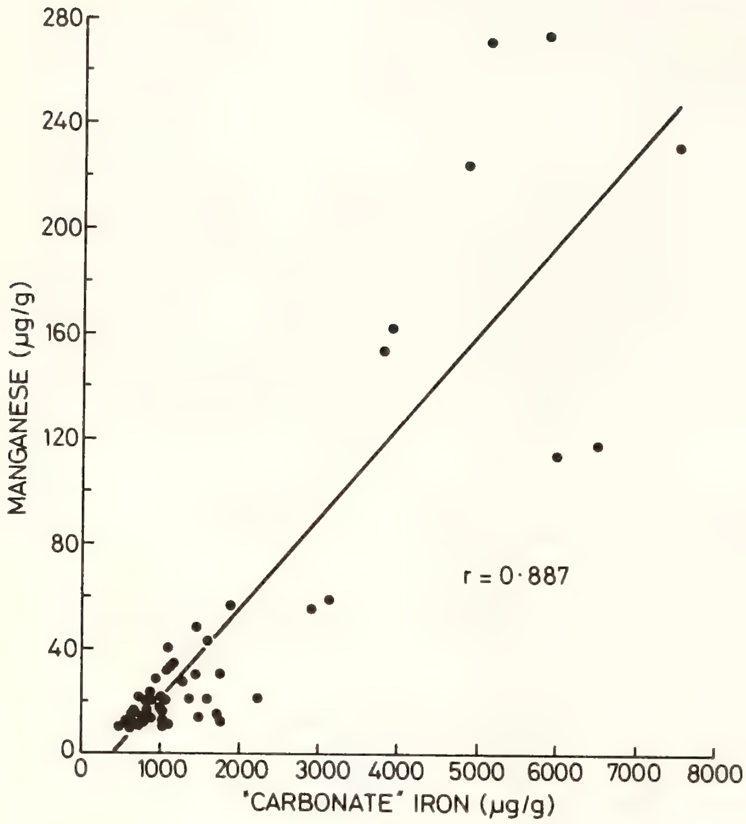


Figure 1. The correlation between manganese in siderites, from the Lithgow seam, New South Wales, and "carbonate" iron.

stages of coalification) and adsorbed (gained during the later stages of coalification), the association being with carboxylic acid and phenolic hydroxyl groups and possibly with mercapto and imino groups (Swaine, 1977). Trace element-organic associations are prevalent at the early stages of coalification but less so as the rank of coal increases possibly because the increase in aromaticity with rank lessens the binding power of fundamental groups (Swaine, 1992a). There is more information about the associations with mineral (inorganic) matter, where trace elements occur as discrete minerals, as replacement ions in major minerals and adsorbed, for example on clays (Swaine, 1990).

During my initial incursion into trace elements in coal, it seemed sensible to apply Goldschmidt's rules, based on the size and charge of ions, to some coal minerals. Carbonate minerals, namely siderite (FeCO3), calcite (CaCO3) and ankerite (Ca(Fe,Mg,Mn)(CO3)2) showed relatively high concentrations of manganese (Brown and Swaine, 1964). Table 1 gives results for Mn in these minerals, showing that 1% Mn or more occurs in some samples. It is suggested that this is because Mn^{2+} replaces some Fe^{2+} in siderite and some Ca^{2+} in calcite. In ankerite, the question may be posed is Mn replacing some Fe or Ca or both? A study of 56 coal samples from the Lithgow seam, New South Wales, gave indirect evidence for the association of Mn with siderite from the good linear correlation (r = 0.89) between Mn and carbonate iron (that is, total iron less pyritic iron), as shown in Figure 1. In low-rank coals, where there are no carbonate minerals, for example, Victorian Latrobe Valley coals, Mn, Sr, Zn and some other elements are associated with carboxylic acid groups in the organic coaly matter (Swaine, 1992a). As coal matures, these carboxylic acid groups disappear and hence also this cation-organic matter association.

Table 1. Manganese in carbonate minerals in coal (as ppm Mn).

Siderite-($FeCO_3$)	
Tongarra	3000
Benley Tops	10000
Calcite-($CaCO_3$)	
Queensland	2240
Wallarah	10000
Hunter Valley	4650
Ankerite-(Ca [Fe,Mg,Mn)][CO_3]$_2$)	
New South Wales	500-17700 (mean 7500)

BORON AS AN INDICATOR OF MARINE INFLUENCE

Seawater contains 4.6 ppm B compared with less than 0.1 ppm B in most terrestrial waters. This is the basis for using boron to indicate the extent of marine influence on sediments. Initially, boron in clays, especially illite, was used. My attempts to use boron in clays associated with coals were only partially successful and hence boron in coal was investigated. The ranges and mean values for boron in coals from the Sydney Basin are shown in Figure 2 (Swaine, 1962a).

Clean-coal composites were used, that is, samples prepared from subsamples having ash yields of less than 35 per cent. The Illawarra coals are known to have been exposed to freshwater conditions only, whereas the Greta coals have been exposed to marine influences. These effects probably occurred during the early stages of coalification when the organic matter could have retained boron probably by chemical fixation or adsorption. On the basis of boron values it was predicted that the Tomago samples had been exposed to mildly brackish conditions. This led to a detailed geological examination which confirmed the boron-based postulate. An extensive study of Queensland coals indicated that most had only been exposed to freshwater conditions, the exceptions being coals from the Nipan-Theodore area of the Bowen Basin, where it is suggested that they had been exposed to mildly brackish to brackish conditions (Swaine, 1971). After a lapse of about 30 years, this use of boron in coal to indicate marine incursions during coalification was tested extensively on a wide range of Canadian coals, in collaboration with F. Goodarzi, Institute of Sedimentary and Petroleum Geology in Calgary. The assessments were carried out in conjunction with geological information on conditions during coal formation, especially changes in the depositional environment (Goodarzi and Swaine, 1994a). An exception was found by Beaton, Goodarzi and Potter (1991) during research on some lignites from Saskatchewan, where high values for boron were not associated with seawater incursions. High concentrations of boron in these coals deposited under freshwater conditions probably depend on secondary enrichments arising from groundwaters leaching evaporites and associated with extensive fault systems (Goodarzi and Swaine, 1994a). This exception stresses the need to confirm boron values by ascertaining the relevant geological features.

In most coals boron is predominantly associated with the coaly organic matter, clays and sometimes tourmaline. The main evidence for organic boron comes from shortfalls in boron in mineral matter and from the inverse relationship between boron in ash and ash yield (Figure 3). Any boron added to the coal swamp from seawater is invariably diluted to brackish water and boron taken up by the coal is considered to be organically bound.

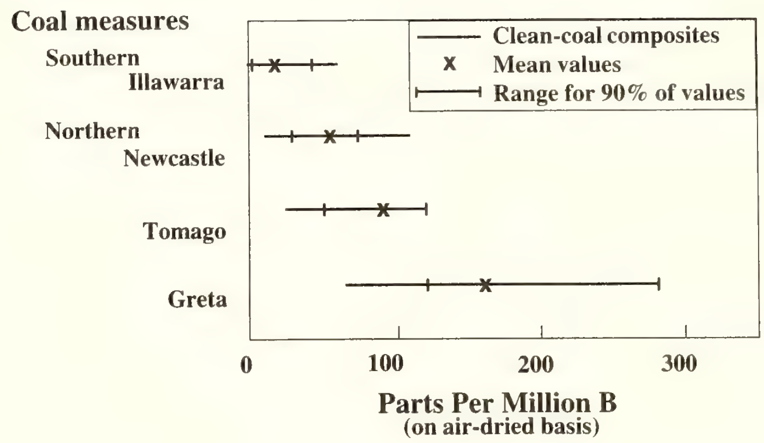


Figure 2. Contents of boron in coals from the Sydney Basin, New South Wales (based on Swaine, 1962a).

As a result of the studies of the Canadian coals, the suggested ranges for freshwater, mildly brackish and brackish influences were modified slightly as follows:

	original	final
Freshwater	<40ppm B	<50ppm B
Mildly brackish	40-120ppm B	50-110ppm B
Brackish	>120 ppm B	>110 ppm B

The original values are based on studies of Australian coals (Swaine, 1962a) and the final values are based on a reappraisal of Australian and Canadian coals (Goodarzi and Swaine, 1994b).

BOILER DEPOSITS

A study of several deposits from the fireside of boilers, using spreader-stokers and chain-great stokers, showed the presence of very high concentrations of several elements, notably phosphorus, boron and arsenic. Some results for the inner layer (1-2 mm thick) and from the outer layer of a deposit on a superheater tube are shown in Figure 4 (based on Brown and Swaine, 1964). There are marked enhancements above coal ash for phosphorus, arsenic, boron, lead and thallium, but not for vanadium. This was the first evidence for

the presence of thallium in an Australian coal. Later, improved methods of analysis showed that most Australian coals had up to about 3 ppm Tl, with a mean of less than 1 ppm (Swaine, 1990). X-ray diffraction identified boron phosphate (BPO_4) in the sample from the inner layer. Further work showed that some deposits contained boron arsenate ($BAsO_4$) in solid solution in boron phosphate (Swaine and Taylor, 1970). These two compounds have not been found in nature. As predicted by Goldschmidt they are isostructural with ß-cristobalite. Phosphate-rich deposits are not found in modern boilers using pulverised coal burnt with excess oxygen. It seems that these deposits are only formed under certain conditions when lump coal is fired relatively slowly. During combustion an initial reaction between quartz, fluorapatite and coal could yield phosphoric acid (P_2O_5) which could react with boron oxide (B_2O_3) to produce boron phosphate.

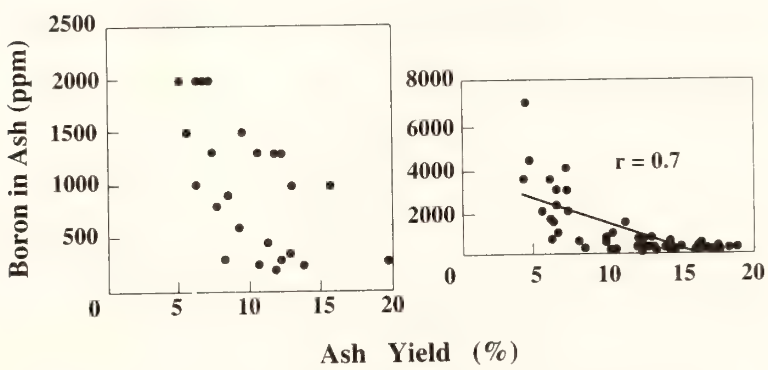
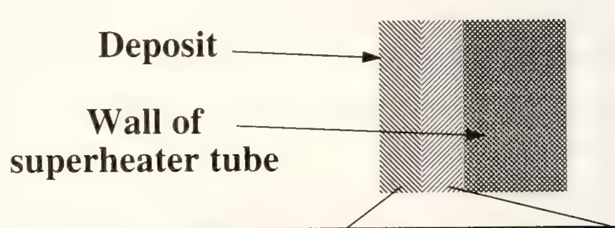


Figure 3. Boron contents in ash versus ash yield for coals from the Theodore district, Queensland (on the left) and from the northern part of the Sydney Basin, New South Wales (Goodarzi and Swaine, 1994a).

FLUORINE IN COAL

As I.P. Pavlov has aptly stated "No matter how perfect a bird's wing may be, it could never lift the bird to any height without the support of air". Facts are the air of science. In environmental science, facts, that is , proper results, are paramount, and hence much attention has been paid to the sampling and analysis of coals for trace elements mostly present at ppm or sub-ppm levels. As an example of the vigilance required to ensure the attainment of proper results, we found that the standard method for determining fluorine in coal (ASTM, 1979) gave low and sometimes very low results for Australian and overseas bituminous coals. This led to the development of a new method (Godbeer and Swaine, 1987) in which the coal sample is mixed with finely ground silica and pyrolysed in a silica furnace at about 1200^{0}C in an atmosphere of oxygen and water vapour, the resulting gases being passed into a sodium hydroxide solution. The absorbed fluoride is determined by an ion selective electrode or by ion chromatography. This pyrohydrolysis method is the basis of the current Australian Standard Method (AS, 1989) and of the proposed International Standards Organisation method.

Why does the ASTM method give low results? In the ASTM method coal is combusted in an oxygen-charged calorimeter bomb, so it seems that not every fluorine-containing mineral is decomposed. Certainly fluorapatite, which is the main source of fluorine in most coals, and probably clays release their fluorine in the bomb, but resistant minerals, for example, fluorite, tourmaline and topaz, may not be completely



Element	Coal Ash	Outer Layer	Inner Layer
P	3000	17000	260 000
As	10	<1	10 000
B	100	150	50 000
Pb	80	40	10 000
Tl	< 20	<20	800
V	150	150	100
Values are in ppm			

Figure 4. Contents of some elements in a deposit on a superheater tube (based on Brown and Swaine, 1964).

decomposed. However, these minerals would release their fluorine in the pyrohydrolysis method which is also used to determine fluorine in rocks.

The pyrohydrolysis method has been used to determine fluorine in representative samples of Australian (Godbeer and Swaine, 1987) and Canadian coals (Godbeer, Swaine and Goodarzi, 1994). It is suggested that the range of values for most coals is 20-500, with a mean of about 150, ppm F (Swaine, 1990).

DEPOSITION FROM THE ATMOSPHERE

Deposition refers to the amounts of elements reaching the earth's surface from the atmosphere. The most important aspect of trace elements in coal is their relevance to environmental matters, especially those connected with the combustion of coal for power generation. Of the twenty five trace elements regarded as being of environmental interest, twelve are included in the list of hazardous air pollutants under investigation by the US Environmental Protection Agency. Hence, it is necessary to measure the amount of trace elements in deposition in the environs of power stations. When coal is burnt in a pulverised-coal-fired power station most trace elements are released and then redistributed into bottom ash, flyash (removed by particle attenuation) and fine flyash. The properties of flyash (formation, mineralogy and composition) are reviewed by Swaine (1995). The fine flyash particles, emitted with the stack gases, are dispersed into the atmosphere where chemical changes and agglomeration of the finest particles take place. Deposition from the atmosphere occurs by wet and dry processes. In the case of dry deposition, turbulence and other effects complicate the accession to the earth's surface. The overall situation is shown in Figure 5 (Swaine, 1994).

Measurements of the trace-element contents in deposition from the environs of a modern coal-fired power station were carried out for four years. The power station is at Wallerawang, New South Wales, situated in a mostly wooded area about 120 km northeast from Sydney. The total installed capacity is 1240 MW produced by pulverised coal firing. Particle attenuation is by electrostatic precipitation. The bituminous feed-coal is from the Lithgow seam with low total sulfur content (0.6% S). The deposition was collected using cleaned *Sphagnum cristatum* moss held in flat, fine-mesh envelopes which were mounted in aluminium frames attached to aluminium stakes so that the frames were 2 m above ground. Locations were chosen at different distances and aspects from the power station. Full experimental details are given by Swaine, Godbeer and Morgan (1989) and by Godbeer and Swaine (1995).

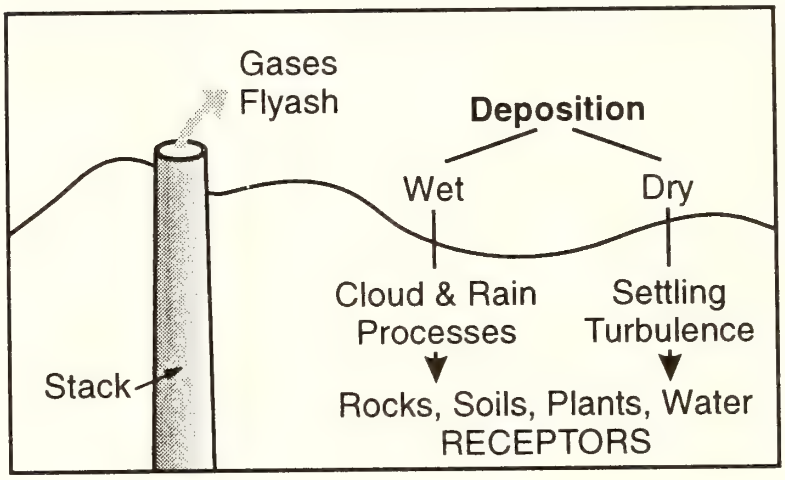


Figure 5. Schematic of the fate of trace elements in stack emissions (reprinted from Swaine (1994) with kind permission from Elsevier Science, Amsterdam).

An important property of flyash is that the concentration of many trace elements increases with decrease in particle size (Figure 6). Samples of flyash removed by the electrostatic precipitators at Wallerawang power station showed increases in concentration for arsenic and germanium with distance from the boiler with maxima at the outlet to the stack (Figure 6; Swaine, 1994). The maximum values are clearly because of the high content of -2.3 μm particles. This means that many trace elements in the stack emissions have higher concentrations than in bulk flyash.

The results of the Wallerawang investigation showed that

(a) The amounts of trace elements in deposition samples decreased with distance from the power station.

(b) The amounts of trace elements deposited at different locations vary significantly with the time of sampling, as shown in Figure 7 for lead at Location A (1.8 km from the power station) and at location P (27.4 km to the north). Location P is taken as background, that is, virtually unaffected by power station emissions. The patterns of results depend on the distance and aspect from the power station.

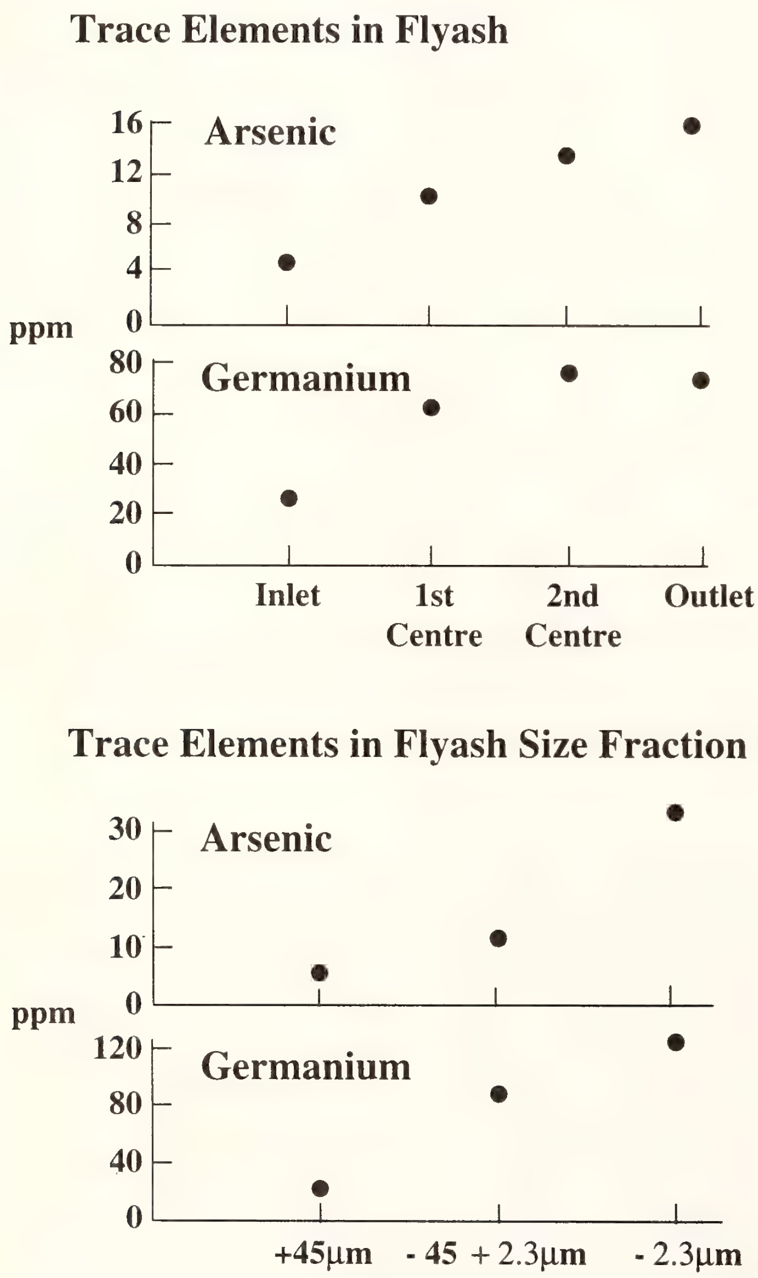


Figure 6. Contents of Arsenic and Germanium in flyash size fractions and in samples from different electrostatic precipitators. (Reprinted from Swaine (1994) with kind permission from Elsevier Science, Amsterdam.)

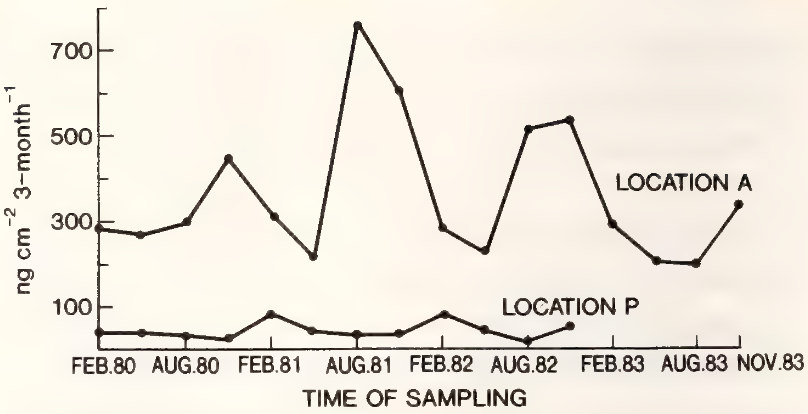


Figure 7. Temporal variations in the deposition of lead at Location A (1.8 km from Wallerawang power station) and at Location P (27.4 km to the north).

These results stress the importance of the time of sampling at any location and that meaningful results cannot be obtained by short-time sampling.

(c) Wind direction and strength, topography and micrometeorological factors are probably the main determinants for the different results at various locations.

(d) The validity of the method was confirmed by the close agreement between the sum of two 3-month results and one 6-month result at particular locations. This confirms the efficiency of moss as a collector, the retention of trace elements by the moss and the precision of the analytical results.

Although it was known that moss has a definite cation exchange capacity, how it retains fine particles had to be ascertained. This was shown by scanning electron micrographs of moss before and after exposure (Figure 8) where the particles of flyash (spherical) and soil/rock (angular) are sited in holes and folds in the moss structure. It was pertinent to ask the question "can we estimate the proportions of flyash and soil in samples of deposition?" This was achieved by using the concentration of germanium in the samples of deposition, on the basis of the difference in the concentrations of germanium in emitted flyash (75 ppm Ge) and in soil/rock particles (1-2 ppm Ge). Using this ratio as a correction factor, the proportions of trace elements in flyash in deposition samples were calculated and

compared with the total deposition, for example, for zinc (Figure 9; Godbeer and Swaine, 1995). It was found that the proportions of flyash in deposition varied greatly at any location. For example, at 1.8 km from Wallerawang, flyash varied from 7-80, with a mean of 40%, and at 5.3 km the proportions were <1-5, with a mean of 2.5% (Swaine, 1994).

The assessment of results and their relevance are very important in environmental science. Results for trace elements in samples of deposition can be put into perspective by comparing them with the amounts contributed by rock weathering (Bowen, 1979), litter decay (Bowen, op. cit.) and fertilisers (based on Swaine, 1962b). Data for arsenic, cadmium, copper and selenium are given in Table 2. For trace elements, atmospheric deposition in the Wallerawang area is not the major source, except for selenium. Selenium is one of the few elements reaching the atmosphere from coal burning in amounts that should be taken into consideration in an environmental assessment.

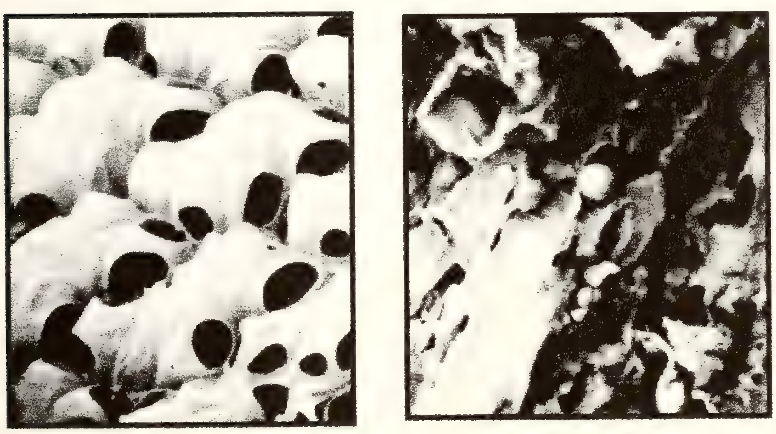


Figure 8. Scanning electron micrographs of the surface of moss before exposure (on the left) and after exposure (on the right). Note the spherical particles (flyash) and the angular particles (soil/rock). Scale : 7 mm = 10 μm. (reprinted from Godbeer and Swaine (1995) with kind permission from Kluwer Academic Publishers, Dordrecht).

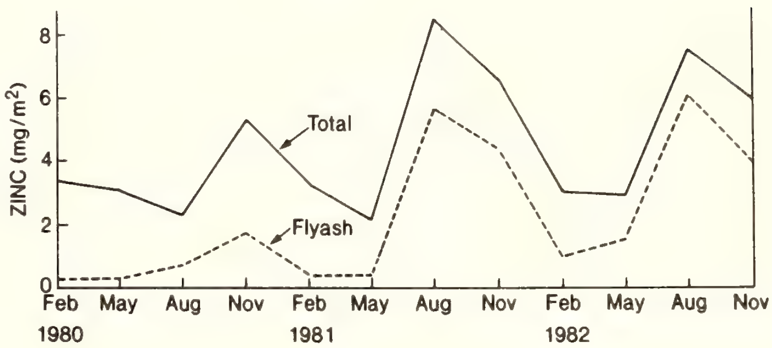


Figure 9. Temporal variations in the deposition of zinc, showing the totals and the proportions in flyash. (reprinted from Godbeer and Swaine (1995) with kind permission from Kluwer Academic Publishers, Dordrecht).

CONCLUDING REMARKS

It is clear that coal will be used increasingly as a major source of power for at least the next decade and hence more attention will be paid to environmental and health aspects (Swaine, 1992b). In this connection, the role of trace elements is important especially in the areas of combustion and waste disposal. In his Will, Liversidge stated that the most important part of the Lecturer's duty shall be to point out in which directions further researches are necessary. Here are some suggestions for future work:

1. Speciation of trace elements, especially those of environmental significance, for example, beryllium, boron, chromium, molybdenum and vanadium.

2. The determination of the isotopic ratios of B_{10} to B_{11}, as a refinement of the use of boron in coal as an indicator of marine influence.

Table 2. Annual deposition in area around Wallerawang power station compared with annual inputs from rock weathering, litter decay and fertilisers (as mg/m^2).

Element	Distance from power station (km)	Deposition	Rock weathering	Litter decay	Fertilisers
Arsenic	1.8	0.80	0.04	0.20	2.4
	6.6	0.12			
	27	0.08			
Cadmium	1.8	0.09	0.003	0.15	0.02
	6.6	0.06			
	27	0.04			
Copper	1.8	6.4	1.3	8	0.16
	6.6	2.3			
	27	0.7			
Selenium	1.8	0.42	0.00013	0.02	0.05
	6.6	0.22			
	27	0.14			

3. The associations of trace elements in bottom ash and flyash in order to assess leaching from power station wastes.

4. Speciation in flue gas and stack emissions, especially for arsenic, chromium, mercury and selenium.

5. More data on trace elements in deposition in the environs of power stations.

6. Investigations of the fate of trace elements in bottom ash-flyash disposal areas in relation to nearby underground and surface waters.

7. Possible health effects from trace elements during the mining and usage of coal.

Although these matters are of great practical interest, indeed concern, the answers will need good research using sophisticated methodology. This is the interface between basic science and technology, the key to successful outcomes in practical problems. It is clear that many tasks in geoscience and environmental science need chemistry for successful conclusions. Emotional statements about possible health effects related to trace elements should be avoided. It is pertinent to keep in mind the sixteenth century dictum of Paracelsus "All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy". The essentiality of many elements is of paramount importance and must be considered together with the possibility of toxicity.

It is clear that trace elements have, and will continue to have, a prime niche in coal science and technology, especially the environmental aspects. If proper care is taken, then it seems most unlikely that trace elements from coal mining and usage should be harmful (Swaine 1989). This does not mean that there should be any complacency. Indeed, continued research is essential, especially on new coals.

It seems fitting to finish with a statement from Nikos Kazantzakis "True teachers use themselves as bridges over which they invite their students to cross; then having facilitated their crossing, joyfully collapse, encouraging them to create bridges of their own". A plea is made for there to be some memorial to Liversidge in the School of Chemistry at The University of Sydney.

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DOCTORAL THESIS ABSTRACT

European impact on Lake Sedimentation in Upland Eastern Australia: Case Studies from the New England Tablelands of New South Wales

Robert J. Haworth

Analysis and dating of sediments from three lake basins set in typical farming country of upland northern New South Wales revealed dramatic environmental changes triggered by the 19th century changeover from Aboriginal to European land use.

European settlement set off processes in each lake catchment that led to a relatively short period of massive sedimentation, followed by a return to low mineral sedimentation rates.

The sedimentation plugs from all three lakes were characterised in the core dating profiles by an unexpected inversion of the exponential decline of the isotope Lead-210 (Figure 1).

This is interpreted as indicating rapid deposition, following extreme catchment erosion, of subsurficial material deficient in Lead -210. Lead-210 is an atmospherically-derived isotope which has a half-life of only 22.6 years, and therefore a measurable life in soil and sediment profiles of less than 200 years.

The uncharacteristic blip in the Lead-210 profiles marking subsoil deposition demonstrated the use of the isotope as both a sediment tracer and a dating device.

Both functions were tested and correlated with a suite of other forms of sediment analysis, including mineral magnetic measurements, loss on igntion determinations and changes in the frequency of native and exotic pollens.

Another consequence of settlement was greatly increased inputs to the lakes of those chemicals most associated with industrial-based agriculture, lead and phosphorus. The combined effect of siltation and nutrient enhancement boosted th e primary productivity of the lakes and transformed largely open water bodies to reed-choked swamps.

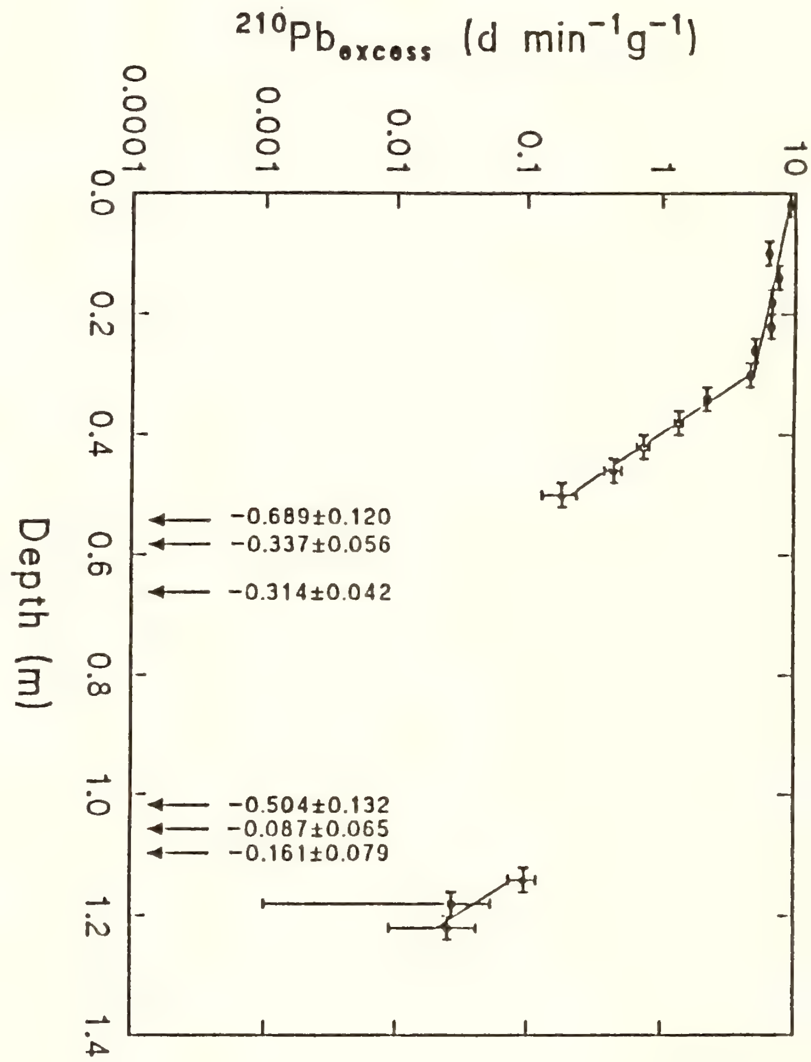

Figure 1. The marked crosses show the excess Lead-210 profile of a representative lake core, with a midcore break in the expected downcore decline of excess Lead-210.

Despite a higher than expected pre-European sedimentation rate from at least one site (Figure 2), the impact of European settlement was enormous, with over half the quantity of post-contact sediment being washed into the basins in less than 25 years. The rapid movement of the material to

the lake basins appears to have depleted all readily available sediment sources in the catchments. The lower sedimentation rates that followed the initial infill seem to be more a reflection of this depletion than any particular land use practice or climatic pattern.

The preferred explanation for the change to lower sedimentation rates after the periods of post-contact disturbance is that deposition in the lakes moved from a process-controlled regime. Despite extensive changes in land use and settlement pattern pattern in the last 100 years, as well as some climatic variation, the rate of supply of sediment to the lakes appears to be controlled manily by the rate at which fresh regolith becomes available on the cathchment slopes. Mobilisation of fresh material is more likely to result from poorly managed engineering works than the local farming practice of grazing and small crop rotation.

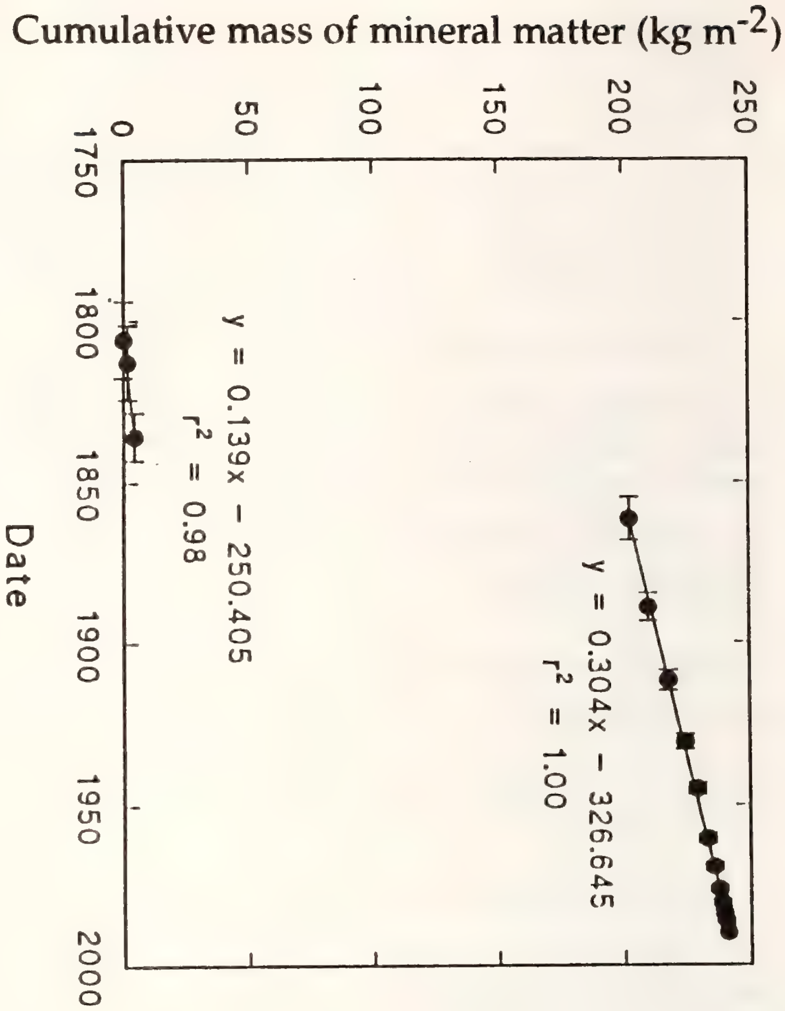

Figure 2. The minerogenic sedimentation rate based on the dating profile (CRS model). Note the general similarity between the pre-European and post disturbance sedimentation rates, and the overwhelming dominance of immediate post-settlement (~1840-1860) sedimentation. (Diagrams by S.J. Gale).

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DOCTORAL THESIS ABSTRACT

Geometry and Structural Evolution of the Leichhardt River Fault Trough, Mount Isa terrain, Australia.

Mark G. O'Dea

The Leichhardt River Fault Trough of the Mount Isa terrain comprises middle Proterozoic sediments, bimodal volcanic rocks and plutons that record processes of intracontinental rifting followed by crustal shortening and metamorphism. It displays superb examples of rift basin development, basin inversion and strike-slip faulting, and offers an opportunity to examine the superposition of extensional and compressional geometries within a spectacularly exposed stratigraphic sequence. This thesis documents the rifting history and resultant rift-basin geometries of the Leichhardt River Fault Trough and incorporates this rifting history in the interpretation of local and regional geometries.

Between *ca.* 1800 and 1600 Ma, igneous and sedimentary rocks were formed and deposited during at least four episodes of superimposed rifting and associated post-rift subsidence. This protracted extensional history resulted in a succession of stacked intraplate rift basins in which strata of Cover Sequences 2, 3 and 4 accumulated.

Strata ranging from the of Mount Guide Quartzite to Lena Quartzite (lower Cover Sequence 2) were deposited and extruded within the N-S oriented Leichhardt Rift, during a period of regional E-W extension. Thereafter, a period of N-S extension resulted in the development of N-tilted half-graben comprising syn-rift strata ranging from the Pickwick Metabasalt to the Whitworth Quartzite (upper Cover Sequence 2). The Lochness Formation and Quilalar Formation were deposited during a period of regional post-rift subsidence.

Deposition of the Quilalar Formation was terminated by a period of E-W extension, footwall uplift and erosion, resulting in the development of the Bigie Unconformity. This unconformity was overlain at approximately 1709 Ma by the syn-rift Bigie Formation and Fiery Creek Volcanics (Cover Sequence 3). A subsequent period of E-W extension, footwall uplift and erosion resulted in the complete bevelling of Cover Sequences 2 and 3 and the development of the Surprise Creek Unconformity. This erosional surface was overlain by rift-related sheet sands of the Surprise Creek Formation, and dolomitic sag-phase sediments of the Mount Isa Group (Cover Sequence 4). Reconstructed stratal geometries are asymmetric in cross-section, indicating that rocks of Cover Sequences 3 and 4 accumulated on the hangingwalls of large E-dipping tilt blocks. Following the deposition of Cover Sequence 4, a subsequent N-S extension event resulted in the development of numerous E-W trending synclines in the hangingwalls of E-W striking normal faults.

Crustal extension was interrupted prior to the formation of oceanic crust by the compressional Isan Orogeny (*ca.* 1590 to 1500 Ma). The inherited extensional fault architecture and the depositional geometry of rift-sag sequences strongly influenced the structural patterns during shortening. Within the Crystal Creek Block, buttressing against rigid footwall blocks of pre-existing rift faults led to the inversion of an underlying half-graben and the amplification of a pre-existing E-W trending syncline. E-W trending folds in the June Hill Block and Horse's Head Block also formed as the result of drag against normal faults during rifting and/or as the result of buckling against competent blocks during basin inversion.

In contrast to the Crystal Creek Block, the Lake Julius Syncline may have formed as a rotational strike-slip "popout" during the waning stages of the Isan Orogeny. Reverse faulting occurred as a bend in the Lake Julius strike-slip fault system was removed, causing an originally

N-S (?) trending syncline to be rotated counterclockwise over a distance of several kilometres, towards a WNW-ESE orientation. In comparing results from the Lake Julius Syncline with those within the Crystal Creek Block, it is apparent that structures of similar orientation and style may have radically different origins and regional significance.

Solutions to some of the most perplexing geometrical problems in the Leichhardt River Fault Trough can be found through an understanding of the original rift basin geometry. Other solutions require an appreciation of the interaction between this rift basin geometry and regional shortening. Recognising the interaction between extensional fault architecture, stratigraphic geometry and regional shortening is critical to interpreting the structural evolution of the Leichhardt River Fault Trough and the Mount Isa terrain.

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DOCTORAL THESIS ABSTRACT

The Effects of Chronic Cerebral Hypoperfusion in the Rat.

Lali H.S. Sekhon

It is the aim of this thesis to examine the effects of chronic cerebral hypoperfusion on brain parenchyma in the rat. This objective would be of great clinical relevance since currently to date no systematic studies have evaluated chronic cerebral hyoperfusion. a rat arteriovenous fistula model was utilised which effectively reduced global cerebral blood flow (CBF) by 25-50% in the absence of cerebral infarction, maintained for twenty-six weeks.

Part One of this thesis is concerned primarily with a review of the literature relating to arteriovenous malformations (AVMs), with particular emphasis on the studies of cerebrovascular steal and animal models of AVMs. subsequent to this, select comments have been made concerning cerebral ischaemia, both acute and chronic.

Part Two presents studies on the pathological effects of the chronic cerebral hypoperfusion in the rat. Initially, the changes occurring as a result of the systemic haemodynamic alterations are examined, followed by a formal evaluation of changes in neural tissue structure that may have occurred as a result of the chronic cerebral hypoperfusion. an initial light microscope survey was followed by transmission electron microscopic studies.

Part Tree evaluates alterations in neuronal function that occur as a result of chronic cerebral hypoperfusion and explores some of the mechanisms involved using electrophysiological in vitro hippocampal slice experiments.

Finally, Part Four of the thesis has attempted to draw together the structural and functional in vitro studies to look for changes in whole animal in vitro behavioural functioning, with an array of behaviousral experiments presented.

The conclusions made in Part Five are that subtle structural, electrophysiological and behioural changes are induced in the rat undregoing 26 weeks of chronic cerebral hypoperfusion. This has not been previously described, with reductions inCBF of this magnitude thought previously to have no effect on the brain.

This thesis represents the first formal experimental assessment of chronic cerebral hypoperfusion. The downfalls of previous studies and strengths of this survey have been discussed. A portfolio of varied experimental approaches have provided a mosaic of the changes in apparently'normal' brain that occur as a result of chronic cerebral hypoperfusion, and have suggested that established opinions on the thresholds of cerebral ischaemia in the chronic state need modification. a new subtype of chronic cerebral ischaemia has been postulated to exist and is described. Typical of any initial survey of this magnitude, dealing with areas that were previously ill-described, many controversial conclusions have been drawn and many questions have been raised. The mechanisms responsible for the changes are not known. Precise quantification of the pathological changes is yet to be done. The effects of revascularization are also unknown. It is hoped that this thesis stimulates ongoning interest and further work into the areas of chronic ischaemia and AVM-induced hypoperfusion, so that these and other questions may be answered in the not too distant future.

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DOCTORAL THESIS ABSTRACT

Situating Style: an Ethnoarchaeological Study of Social and Material Context in an Australian Aboriginal Artistic System.

Claire Smith

This is an ethnoarchaeological study of style in the visual arts of Aboriginal people living in the Barunga region of the Northern Territory, Australia. The main concern is the development of a practical framework for the analysis of style in indigenous visual arts. This framework integrates the notions of style, semiotics and social strategy in an attempt to deal with the dynamics of image creation and perception.

The principal result is that the morphological characteristics of style are influenced systematically by the historically situated positions of both producer and interpreter, and by the differing strengths, possibilities and constraints of different raw materials. Moreover, each raw material has inherent qualities that make it particularly suitable for specific social uses. Since different media within an artistic system are likely to exhibit a unique combination of stylisitic characteristics, including differing degrees of diversity, it is incorrect to assume that a single art form will be indicative of an artistic system as a whole.

Research needs to be focussed clearly on the contexts in which archaeological art occurs, and comparative studies need to compare like with like. Single explanations are unlikely to be sufficient since it is most likely that they tell only part of the story. In addition, seemingly anomalous evidence should not be discounted, but should be used as a basis for enquiry into the likelihood of alternative scenarios that co-exist with the main explanation.

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"THE VOLCANIC EARTH" BY F. LIN SUTHERLAND

An Illustrated Volume on the Dramatic Role of Volcanism in the Comprehensive Geology of the Australasian Region as related to other Active World Phenomena in the framework of Modern Scientific Knowledge.

REVIEWED by John C. Grover, O.B.E.

This is a remarkable book by the Principal Research Scientist, Dr. Lin Sutherland FAIG of the Australian Museum, Sydney. The thought given to its structure and content does great credit to the Author. It reflects a competent Scientist, the extent of his travels to see ground truth and to meet with those who shared his dedication to understanding modern theories of geology, geophysics and geochemistry. The cheerful leader, his proficient local team, and the scientific photographers in other countries, have been backed by the Australian Museum Trust to produce a volume of importance, different from the usual text-book. Opposite a photograph of a lava fountain eruption, its opening paragraph conveys the simplicity and clarity of the text:

Volcanoes create vivid events. Fountains of molten lava, bursts of gas and showers of rocky debris explode from their vents. Glowing avalanches or streams of lava pour down their slopes. Eruptive clouds may rise to stratospheric heights. Landscapes can be buried, rivers disrupted, lakes overwhelmed and local people endangered. Activity may last a few hours or continue over a decade. Some volcanoes erupt once only, others again and again. Vents may lie dormant for long periods between eruptions and eventually become extinct.

The quality end product is a source-book for those interested in clearly-written explanations of the many facets of geology, in which volcanoes have and will continue to play a part. This book will be as much for senior students in secondary schools and for undergraduates as for graduate earth scientists and the intelligent laypersons who need to know about the local environment.

Unusual is the coverage of urban, suburban and regional Eastern Australia, the updated knowledge of very recent past eruptions promoting thoughts of re-awakening volcanism where there has been none at all for a very long time. Nor will it happen tomorrow; but the evidence suggests that this exemption of Australia from active volcanism cannot last forever. The volcanism near Sydney, Melbourne, Geelong, Mt Gambier, Brisbane, and Atherton has not been ignored, nor that of the populated north of Tasmania. There was a time long ago when these areas were not immune from dynamic volcanic events. So that people can see the volcanic effects in their areas, these populated parts are shown in maps in Appendix I. The well-known underlying hotspots have been put into perspective with additional information and mapped (p.215). Of the volcanoes in populated Eastern Australia, Dr Sutherland writes:

About thirty central volcanoes, with scenic peaks of rhyolite and trachyte, rise from their basaltic aprons. They extend from CAPE HILLSBOROUGH VOLCANO in North Queensland down through the eastern hinterlands to the MACEDON VOLCANO in Victoria.. Apart from the older central volcanoes around Rockhampton, all show a common trend: they become younger to the south, decreasing from 33-44 million years old around Hillsborough to 6-8 million years old in central Victoria. This migration was noticed by scientists from Australian National University after they had dated

many central volcanoes. They explained this southward sweep by a simple plate tectonic model. The Australian plate (lithosphere), drifting slowly northwards from where the Southern Ocean opens, passes over deep upwellings (hotspots) in the underlying mantle (asthenosphere). In other words, each volcano was formed over a hotspot, then became carried away with Australia's movement. This created an ever-lengthening chain of extinct volcanoes (see p.91 onwards).

Shown is a photograph of Australia's only active volcano -- Big Ben on Heard Island. Others occur in the various Antarctic territories. Shown also is Mount Erebus Volcano which daily contributes about a thousand tonnes of chlorine gas to the infamous ozone hole above it, according to reports.

The contrasting active volcanic region of New Zealand has been well covered, the rest of the island festoon to our east and north-east rather lightly, lest the book size be too great. However, volcanic areas of Lord Howe Island and its nearby volcanic neck, Ball's Pyramid, will interest visitors, as will the photographs and brief descriptions of Rabaul and its eruptions of 17 September 1994. Colour photographs and descriptions of eruptions all over the world add to the readers' comprehension of the Australasian and South-East Asian scene. All of this is set within the framework of the Plate Tectonic Theory and sea floor spreading from mid-ocean ridges. Submarine volcanoes and geographical implications, the extinction of dinosaurs and the iridium anomaly graph, comparisons with other planets, radio-carbon and luminescence in dating, so-called passenger minerals including diamonds in NSW – and rock products of volcanoes have not been forgotten. Dr Sutherland's knowledge of gems is apparent. Of diamonds he writes:

Australian diamonds come from three general regions. In the western region, the main area, – Kimberley in Northwestern Australia ñ contains lamproite, and kimberlite pipes. Some carry diamonds brought up from depths of 150 km. The prolific Argyle pipe is the main producer.

The book's main headings are as follows:

1. Preliminary Eruption. 2. Main Eruption: the Volcanoes. 3. Overall Eruption: Volcano Distribution. 4. Post-Eruption: Dating Volcanoes. 5. Epi-Eruption: Volcanic Environments. 6. Future Eruption: Volcano Watch. 7. Sub-Eruption: Plate Tectonics. 8. Volcanic Forms around Australia. 9. Volcanic Disruptions Around Australia. 10. Volcanic Minerals and Rocks Around Australia. 11. Dynamic Volcanoes Around Australia. 12. Future Volcanoes Around Australia. 13. Trans-Tasman Volcano Spotter's Guide. APPENDICES: I. Maps of Australian and New Zealand Volcanic Areas. II. Some Significant Eruptions (from circa. 1620 to 1994). III. Typical Minerals of Volcanic Rocks. BIBLIOGRAPHY. GLOSSARY. INDEX.

The smaller print Bibliography is subdivided into the various volcanic subjects, each in three gradings, A, B and C related to readers' interest levels. The detailed Glossary of Terms, also in smaller print, covers 6 pages of two columns. The Index also is detailed and of a high standard.

More details might have been given of the important catastrophic explosion of Mount Lamington, whose glowing avalanches in Papua Niugini in 1951 destroyed all life in an area of 98 square miles. It was, however, pleasing to see mention of the Australian Volcanologist, Mr G.A.M. (Tony) Taylor, who was awarded the George Cross for courage in his investigation of that eruption. Though it occurred before the days of modern colour photography, the lessons were great and many. The loss of life was most unfortunate, to say the least, because lay officials ignored obvious warning signs.

Those au fait with colour processes would appreciate the amount of work involved. Superbly illustrated by hundreds of explanatory photographs

in vivid colour and remarkable clarity, here is a scholarly masterpiece covering a wide field, embellished by modern publishing technology, in itself a credit to the University of NSW Press. Bound with hard cover, circa. A-4 in size, with a vivid dust cover featuring a Japanese eruption, the price is $Aust 49.95.

[Although Australia is free from volcanism, the island festoons to the north and north-east of Australia continue to suffer loss of life from catastrophic volcanic eruptions and great earthquakes. They require the services of trained personnel in these fields]. The reviewer hopes to publish an assessment of thirty years of research in both subjects in the near future, in a volume which has taken seven years to prepare.

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BIOGRAPHICAL MEMOIR

STANLEY KEITH RUNCORN
19 NOVEMBER 1922-5 DECEMBER 1995

Keith Runcorn was elected Fellow of the Royal Society in 1965, whilst he was director of the School of Physics at Newcastle upon Tyne. As a Fellow, he organised many Royal Society Discussion Meetings particularly on topics concerning magnetism, palaeomagnetism, lunar magnetism and the Earthís dynamo. He also organised the analysis of NASA lunar rock samples in the UK. He wrote to each palaeomagnetic laboratory in the UK, to suggest that they should propose experiments to be carried out on a gram of lunar rock sample. The result was an outstanding submission to NASA on the analysis of lunar rock samples, and a reward of lunar rock samples for analysis for those laboratories who took up his suggestion. The samples attracted enormous public attention when they were put on display in Newcastle upon Tyne.

One of Runcorn's principal contributions was the use rock magnetism to show that continental drift was the only way to account for magnetic results observed from sea-floor spreading and for the different magnetic pole positions determined from rocks in different continents. He gave a series of special lectures at the University of New South Wales on the subject of continental drift. The lectures attracted very large audiences (approximately 400 at each of three lectures).

Another major contribution was his remarkable solution of the problem of lunar magnetism. The problem is that the lunar rocks are strongly magnetised, but yet there is virtually no ambient magnetic field at the surface of the Moon. He showed in an article in the scientific journal, Nature, that when the lunar dynamo stopped, the lunar rocks remain magnetised, but that the distribution of the magnetisation, no matter how strong, could not give rise to a magnetic field at the surface.

He was outstanding at organising people and getting things done. For example, he organised readings of electric potential on abandoned undersea cables between Sydney, Auckland, Suva and Fanning island, which continued for over a decade. The work was based on his idea that poloidal electric fields from the Earth's magnetic dynamo might produce differences in electric potential at places which were widely separated. The work showed conclusively that the ocean itself acted as a dynamo, but never resolved the question concerning the Earth's dynamo.

He was a very kindly person and he led a rather unconventional life, preferring to travel continually, and preferred to travel by train wherever possible. He never owned a house, and always stayed in college or hotel accommodation. He also liked to visit his mother who lived in Jersey, and who celebrated her 100th birthday in 1995.

His death at the hands of a burglar caught ransacking his hotel room in the San Diego hotel in December 1995 came as a shock to the scientific community. A few days after his death, the regular monthly meeting of the Royal Astronomical Society was being held in London, and many speakers took the opportunity to pay a tribute to the magnificent contributions Keith made to the geophysical sciences. (D.E.W.)

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BIOGRAPHICAL MEMOIR

JOHN CRAIG CAMERON: 1921-1995

John Cameron died in England on 29 March 1995 at the age of 73 after a long illness. He had been a Member and stalwart supporter of the Society since 1957. He was the Society's Honorary Secretary in 1969 and 1979, Vice-President in 1971, 1973 and 1974, and President in 1972.

John was born and raised with a sister and three brothers in Shanghai, China, before the family returned to Scotland in 1938. He attended George Watson's Boy's college in Edinburgh, and commenced studies at Edinburgh University in 1940. Like so many of his contemporaries, John's education was interrupted by War. He enlisted in the Argyll and Sutherland Highlanders in 1941 and was commissioned to the Royal Engineers. His first posting was to the 82nd African division in Nigeria, and he was subsequently transferred to India, from whence as a Captain in the Royal engineers, he participated in the Burma Campaign.

On demobilisation, John returned to studies at Edinburgh University, graduating with an MA in 1948. He remained at Edinburgh to take a second degree, a BSC with 1st Class Honours in Geology and mineralogy (summa cum laude) in 1951. During his undergraduate years John was a keen sportsman, gaining a Blue for Hockey and Half-Blue for Swimming.

On graduation John joined Royal Dutch Shell and was posted to Shell Condor, in Columbia for three years, before returning to The Hague. Buring his time in Columbia John married Patricia. Their son was born in Barranquilla.

In 1955 John resigned from Shell and in July that year was appointed to a Lectureship in the Department of Applied Geology at the University of New South Wales, Sydney, a position he held until his retirement.

John's interests and responsibilities at the University were related to the broad field of petroleum, and his research and writings were directed to that end. He was a willing, cheerful, and supportive member of the Department's staff, and will be remembered particularly for his work with First Year students, in both field and laboratory.

John continually sought opportunities to update and expand his knowledge of petroleum geology for the benefit of his students. On sabbatical leave, in 1964, he obtained a Diploma in Petroleum Reservoir Engineering at Imperial College (DIC), and in australia attended courses in well-log interpretation, hydrodynamics and hydrogeology, petrofabric analysis, subsurface stratigraphy, exploration geophysics and natural gas engineering.

John maintained a professional involvement in a number of associations and societies, including the American Association of Petroleum Geologists, the Petroleum Exploration of Australia, the Geological Society of Australia, the Royal Society of New South Wales (serving terms as Councillor and President), the Australian Institute of Petroleum, and the Australasian Institute of Mining and Metallurgy. He was ever willing to speak, as occasion required to

professional, government and community groups on the problems of petroleum occurrence in Australia.

John's interests outside his profession were no less divers. He was an active member of the University of New South Wales Hockey Club, and a keen supporter of the Arts and Theatre.

On his retirement at the end of 1981 he moved to Southampton, England, where he continued his professional interests and broadened his academic knowledge (and linguistic abilities) through studies of Latin and Mathematics. John is survived by his wife Patricia and son John.

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(P.R.E.)

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NOTICE TO AUTHORS

A "Style Guide" to authors is available from the Honorary Secretary, Royal Society of New South Wales, PO Box 1525, Macquarie Centre, NSW 2113, and intending authors *must* read the guide before preparing their manuscript for review. The more important requirements are summarised below.

GENERAL

Manuscripts should be addressed to the Honorary Secretary (address given above).

Manuscripts submitted by a non-member must be communicated by a member of the Society.

Each manuscript will be scrutinised by the Publications Committee before being sent to an independent referee who will advise the Council of the Society on the acceptability of the paper. In the event of rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere, nor is likely to be published substantially in the same form elsewhere. Well-known work and experimental procedure should be referred to only briefly, and extensive reviews and historical surveys should, as a rule, be avoided. Letters to the Editor and short notes may also be submitted for publication.

Original papers or illustrations published in the Journal and Proceedings of the Society may be reproduced only with the permission of the author and of the Council of the Society; the usual acknowledgements must be made.

PRESENTATION OF INITIAL MANUSCRIPT FOR REVIEW

Typescripts should be submitted on bond A4 paper. A second copy of both text and illustrations is required for office use. Manuscripts, including the abstract, captions for illustrations and tables, acknowledgements and references should be typed in double spacing on one side of the paper only.

Manuscripts should be arranged in the following order: title; names(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgements; appendices; references; names of Institution/Organisation where work carried out/or private address as applicable. A table of contents should also accompany the paper for the guidance of the Editor.

Spelling follows "The Concise Oxford Dictionary".

The Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigraphic names must conform with the International Stratigraphic Guide and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra, ACT 2601, Australia.

Abstract. A brief but fully informative abstract must be provided.

Tables should be adjusted for size to fit the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

Illustrations. When submitting a paper for review all illustrations should be in the form and size intended for insertion in the master manuscript. If this is not readily possible then an indication of the required reduction (such as reduce to 1/2 size) must be clearly stated.

Note: There is a reduction of 33% from the master manuscript to the printed page in the journal.

Maps, diagrams and graphs should generally not be larger than a single page. However, larger figures can be printed across two opposite pages.

Drawings should be made in black Indian ink on white drawing paper, tracing cloth or light-blue lined graph paper. All lines and hatching or stripping should be even and sufficiently thick to allow appropriate reduction without loss of detail. The scale of maps or diagrams must be given in BAR FORM.

Half-tone illustrations (photographs) should be included only when essential and should be presented on glossy paper.

Diagrams, graphs, maps and photographs must be numbered consecutively with Arabic numerals in a single sequence and each must have a caption.

References are to be cited in the text by giving the author's name and year of publication. References in the reference list should follow preferred method of quoting references to books, periodicals, reports and theses, etc., and be listed alphabetically by author and then chronologically by date.

Titles of journals should be cited in full – *not* abbreviated.

MASTER MANUSCRIPT FOR PRINTING

The journal is printed by offset using pre-typed pages. When a paper has been accepted for publication the text may either be typed by electric typewriter or produced by word-processor print-out. Print-out or typing should be in a column exactly 105 mm (= 4 1/8 inches) wide. Type size should be 14 point (Roman preferred) or 12 pitch single-spaced (IBM Adjutant preferred).

Reprints An author who is a member of the Society will receive a number of reprints of his paper free. An author who is not a member of the Society may purchase reprints.

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THE ROYAL SOCIETY OF NEW SOUTH WALES

The Society originated in the year 1821 as the Philosophical Society of Australasia. Its main function is the promotion of Science through the following activities: Publication of results of scientific investigation through its Journal and Proceedings; the Library, awards of prizes and Medals; liaison with other Scientific Societies; Monthly Meetings; and Summer Schools for Senior Secondary School Students. Special meetings are held for the Pollock Memorial Lecture on Physical and Mathematics, the Liversidge Research Lecture in Chemistry, and the Clarke Memorial Lecture in Geology, Zoology, and Botany.

Membership is open to any person whose application is acceptable to the Society. The application must be supported by two members of the Society, to one of whom the applicant must be personally known. Membership categories are: Ordinary Members, Absentee Members and Associate Members. The Annual Membership fee may be ascertained from the Society's office. Subscriptions to the Journal are welcomed. The current subscription rate also may be ascertained from the Society's office. The Society welcomes manuscripts of research and review articles in all branches of science, art, literature and philosophy for publication in the Journal and Proceedings. Manuscripts will be accepted from both members and non-members, although those from non-members should be communicated through a member. A copy of the Guide to Authors is obtainable on request and manuscripts may be addressed to the Honorary Secretary (Editorial) at the Society's office.

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Stratigraphy and structure of an outboard part of the forearc of the Hikurangi Margin, North Wairarapa, New Zealand

G. NEEF

Abstract. The area studied lies inboard of the trench slope break in the forearc part of the Hikurangi Margin in North Wairarapa, North Island, New Zealand. It lies above a west-subducting Pacific plate. The geology of parts of two units of the forearc (the Tawhero Basin and the forearc ridge) are described. The major NNE-trending Tinui Fault separates the Tawhero Basin from the trench slope break, which lies to its east - it resembles the Mentawai Fault of offshore Sumatra. The NNE-trending Waihoki Fault separates the Tawhero Basin from the forearc ridge which lies to its west. These faults were active during much of Miocene time forming a graben between them. Associated with graben formation was dextral transpression which was caused by oblique subduction of the underlying Pacific plate. The Waihoki Fault has been inactive since 6 Ma.

Most of the strata of the study area comprise Owahanga Group (mid-late Miocene), which are well developed in the northeast-trending Tanawa Syncline, and the Hurupi and the Te Hoe Groups (late Miocene), which are well developed west of the Waihoki Fault. Cretaceous strata (Mangapokia, Te Mai, and Whangai Formations) crop out locally along the western margin of the area. The youngest strata, Waihoki Formation (Te Hoe Group) of Kapitean (latest Miocene) age crop out within the north-trending Tawhero Syncline in the centre of the mapped area. Much of the development of the Tawhero Syncline near Tawhero Station has occurred since early Pliocene time indicating increased compression since then. Associated with this increased compression has been substantial uplift - as demonstrated by the Holocene incision of the meander belts of rivers.

Keywords: Forearc basin, Hikurangi Margin, southern Tawhero Basin, forearc ridge, structure, tectonics, stratigraphy, geological history.

INTRODUCTION

The area studied, ~ 250 km^2 and subrectangular in shape, comprises the southwestern part of 1:50,000 metric topographic map NZMS sheet U25 Pongaroa and an eight kilometre wide north-trending belt adjacent to the western margin of the sheet U25 (Fig. 1). (Grid references and New Zealand fossil record numbers referred to in the text lie in sheets U25 and T25). The southern margin of the study area lies 120 km northeast of Wellington in North Wairarapa, which is a sparsely settled part of New Zealand where the inhabitants are engaged in sheep-cattle farming. Access to the southern part of the

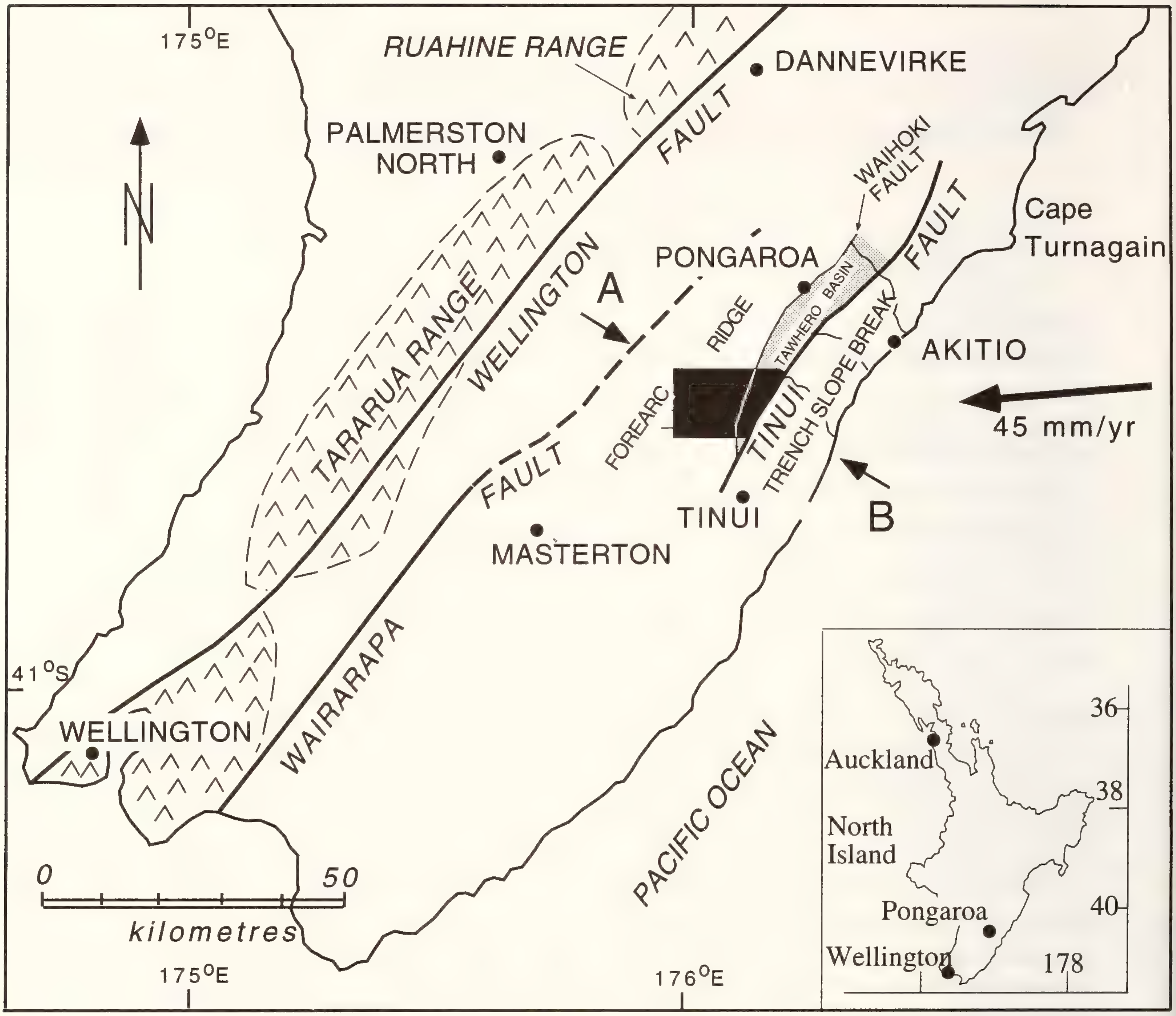


Fig. 1. Map of the southern part of the North Island showing the location of the study area. Also shown is the distribution of the forearc ridge, Tawhero Basin and the trench slope break in North Wairarapa. Offshore the direction and the rate of motion for the Pacific plate relative to the Australian plate is shown by the large arrow.

study area is possible by road, whereas access to the northern part must be largely by foot (especially the northeast). The area is hilly (max. altitude 450 m) and flat land is largely restricted to the valleys of the Tinui and the Whareama Rivers. The strata are well exposed along the banks of rivers and streams and in road cuts. This work is a record of field studies completed during 1982-89 —mostly during the summer of 1982-83— and is illustrated by a geological map (Fig. 2) and a cross section (Fig. 3). The work is largely a description of the early Neogene development of part of a forearc basin lying inboard of the trench slope break and the late Miocene history of the forearc ridge, which lies to its west. It provides and example that is pertinent to the study of Palaeozoic and Mesozoic forearcs of Australia.

PREVIOUS WORK

Ongley (1935) pioneered geological mapping in North Wairarapa and Kingma (1967) mapped the structure and stratigraphy of the area at 1:250,000 scale. More detailed studies of the study area were by Johnston (1975, 1980). Neef (1984; 1995; in press) described the geology west, east and north of the study area. Strata of the Early Cretaceous Pahaoa Group in Wairarapa were described by Moore and Speden (1984) and a clastic dike within the ng_4 Mudstone Member (Neef 1991a) and turbidites of Tanawa, Pakowhai and Waihoki Formations (Neef 1992a) have also been studied previously.

STRUCTURE AND TECTONIC SETTING

The Pacific plate underlies the study area at ~ 14 km (Arabasz and Lowry 1980) (Fig. 4). Subduction of the underlying plate is now oblique, causing tectonics to be partly due to subduction and partly due to dextral displacement (Walcott 1978). Also important to an understanding of Neogene tectonics of the area is the clockwise rotation of the east coast of the North Island during the last 40 m.y. (Walcott 1987). Six units of the forearc, each bounded by a major fault, are known (Neef in prep.). Two of these units, the southern part of the Tawhero Basin, and part of the forearc ridge are described here (Figs. 2 and 4). East of the Tawhero Basin and east of the bounding Tinui Fault Complex is the mid slope break which acts as a back stop and is composed of substantial Early Cretaceous to Paleogene strata. The Tinui Fault Complex has a similar location within the forearc as does the Mentawai Fault which lies offshore of Sumatra (Izart *et al.* 1994). The Waihoki and the Tinui faults together formed a simple dextral shear couple during much of the Miocene (Neef in press) but the amount of dextral displacement along these faults is unknown. Subduction controlled tectonics caused a graben (the Tawhero Basin) to form between the faults during the period 24 - 6 Ma. Because the Waihoki Fault and the Tinui Fault Complex converge southwards, the Tawhero Basin is only 3 km wide at the southern margin of the study area.

The outboard part of the forearc was tectonically active during most of the Miocene (there is ample evidence of faulting along the Tinui Fault in the early Miocene, Neef 1995) whereas during Late Quaternary time faulting was almost entirely in the inboard part of the forearc. This explains why the outboard part of the forearc has been described as the fold and thrust zone whereas the inboard part has been referred to as the strike slip zone (Cape *et al.* 1990).

STRATIGRAPHY

Stratigraphic nomenclature of the study area follows that of Ongley (1935), Johnston (1975), Moore and Speden (1984) and Neef (1991b) (Fig. 5). Because there is little structural complexity and there is good biostratigraphic control (especially from foraminifera examined by Hugh Morgans) in the Neogene of the study area, the production of a geological map was relatively straight forward. Macrofossils in Cretaceous strata are very rare and are chiefly species of the bathyal bivalve *Inoceramus* (Ballance 1993) and Cretaceous biostratigraphy is largely from the occurrence of these bivalves and fossil

Fig. 2. Geological Map of the study area. See Fig. 3 for legend.

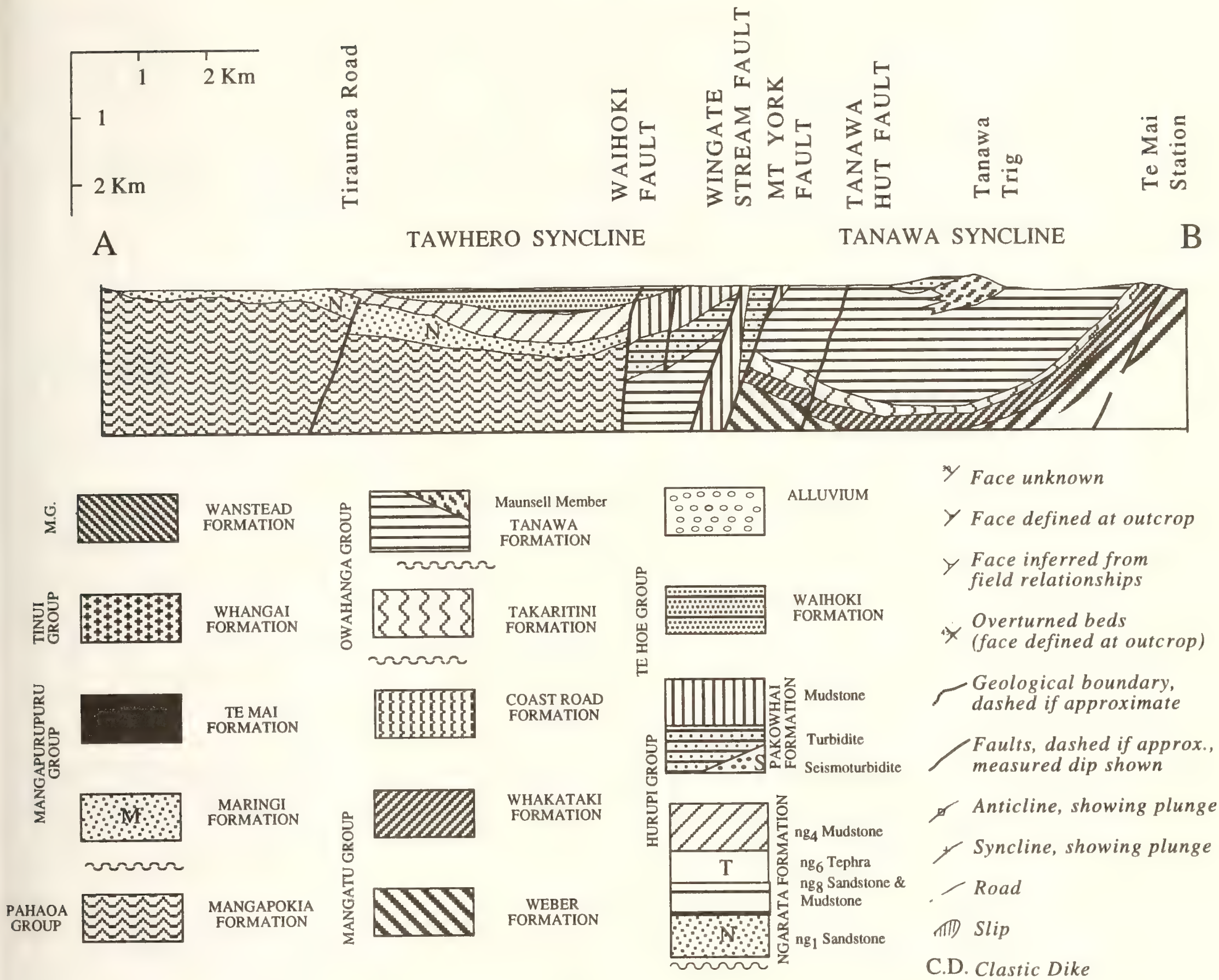


Fig. 3. Geological cross section A-B.

spores are also important (Neef 1995). Characteristically the Cretaceous and Cenozoic formations are uniform in lithology and marker beds within formations are absent - an exception is the ng_6 Tephra Member of the Ngarata Formation. Unfortunately, the Tephra Member is unknown east of the Tawhero Syncline.

The depth of deposition of the Neogene strata is estimated from the inferred depth distribution of fossil foraminifera (Vella 1962; Hayward 1986). Estimations of depth (e.g. upper bathyal (400 - 1000 m) to mid bathyal (1000 - 2000 m Hayward 1986), are most useful in synthesis of the depositional environment.

PAHAOA GROUP

(Moore and Speden, 1979)

MANGAPOKIA FORMATION

(Moore and Speden, 1979)

Distribution: The formation crops out in the following areas: (1) in a 7 km^2 area in the southwestern part of the study area; (2) adjacent to the Wairiri Fault ~ 1 km southeast of Mokai Trig; (3) southeast of Ngarata Station; and (4) in the southern part of the Spring Hill Anticline.

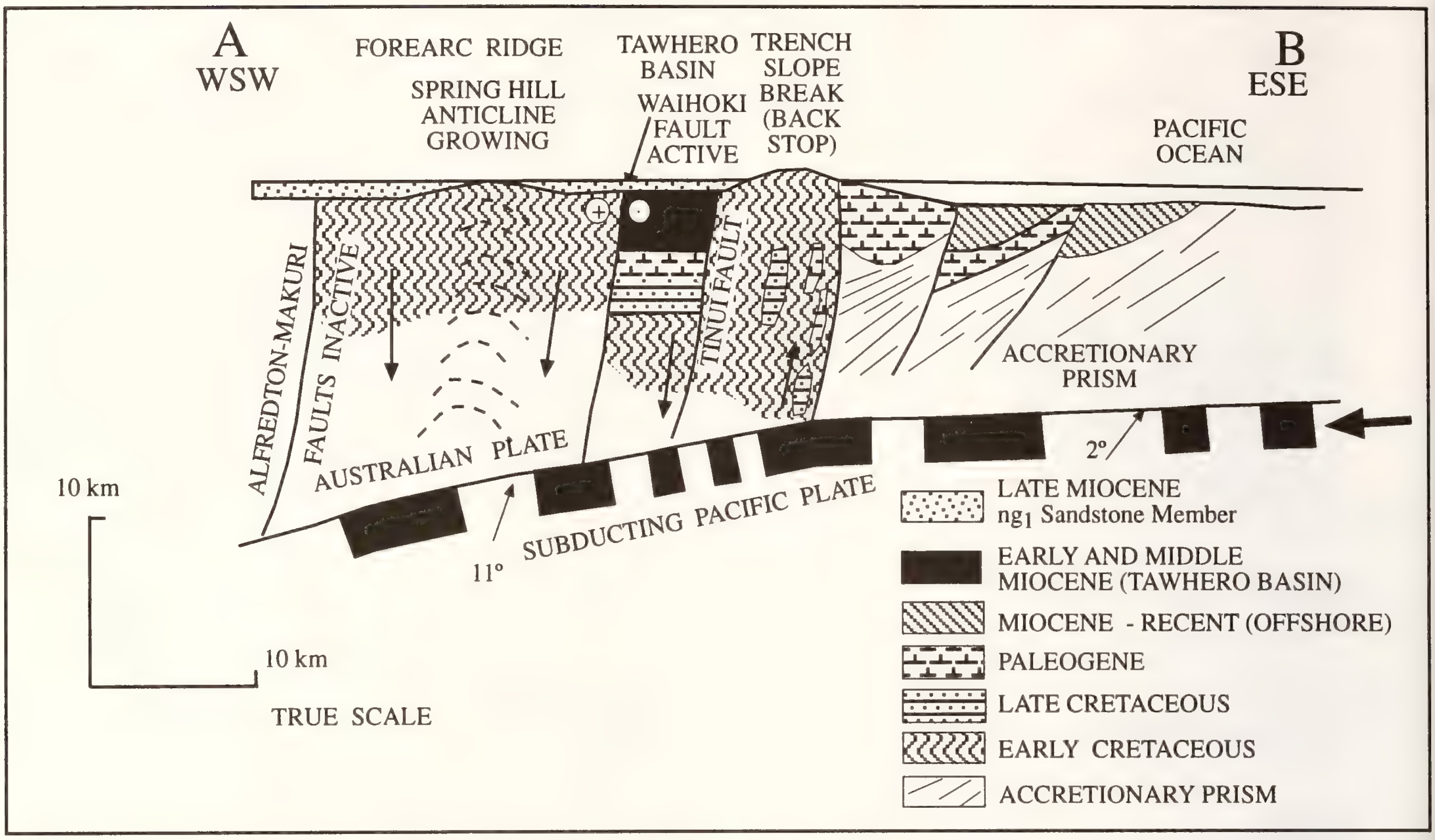


Fig. 4. Diagrammatic section of part of the forearc basin and part of the accretionary prism in North Wairarapa at ~10 Ma (early Tongaporutuan) (partly after Lewis and Pettinga 1993, and Neef in press). For location see Fig. 1.

Description and Thickness: The formation comprises indurated couplets of sandstone and mudstone lacking fossils and evidence of the direction of younging. At two localities in Makirikiri Stream there are float boulders of sandstone containing pebbles. In the north at T25/645541 there is a jaspilite outcrop and a knoll of sandstone crops out at T25/642524.

Age: The Pahaoa Group has a Urutawan? - Motuan Age (Moore and Speden 1984).

Depositional Environment: Most of the original sedimentary structures have been obliterated, however, most of the couplets probably represent facies C2.2 of Pickering *et al.* (1989) which were deposited, perhaps, in a submarine fan environment. Ballance (1993) has proposed an accretionary prism environment of deposition for the formation.

MANGAPURUPURU GROUP
(Johnston 1975)

MAKATOTE STREAM SUBGROUP
(Neef 1991b)

MARINGI FORMATION
(Johnston 1975)

Distribution and Description: The Maringi Formation crops out as a 300 m-wide southeast trending belt ~ 500 m south of Manawa Trig. At T25/650407 the formation comprises pale grey siltstone with 1-2 m long septarian concretions. South of the study area Johnston (1980) discovered an unconformity at the base of the formation.

Age: The Makatote Stream Subgroup of the Mangapurupuru Group has a Motuan - Arowhanan age range (Neef 1995).

Depositional Environment: From its lithology and the absence of macrofossils the

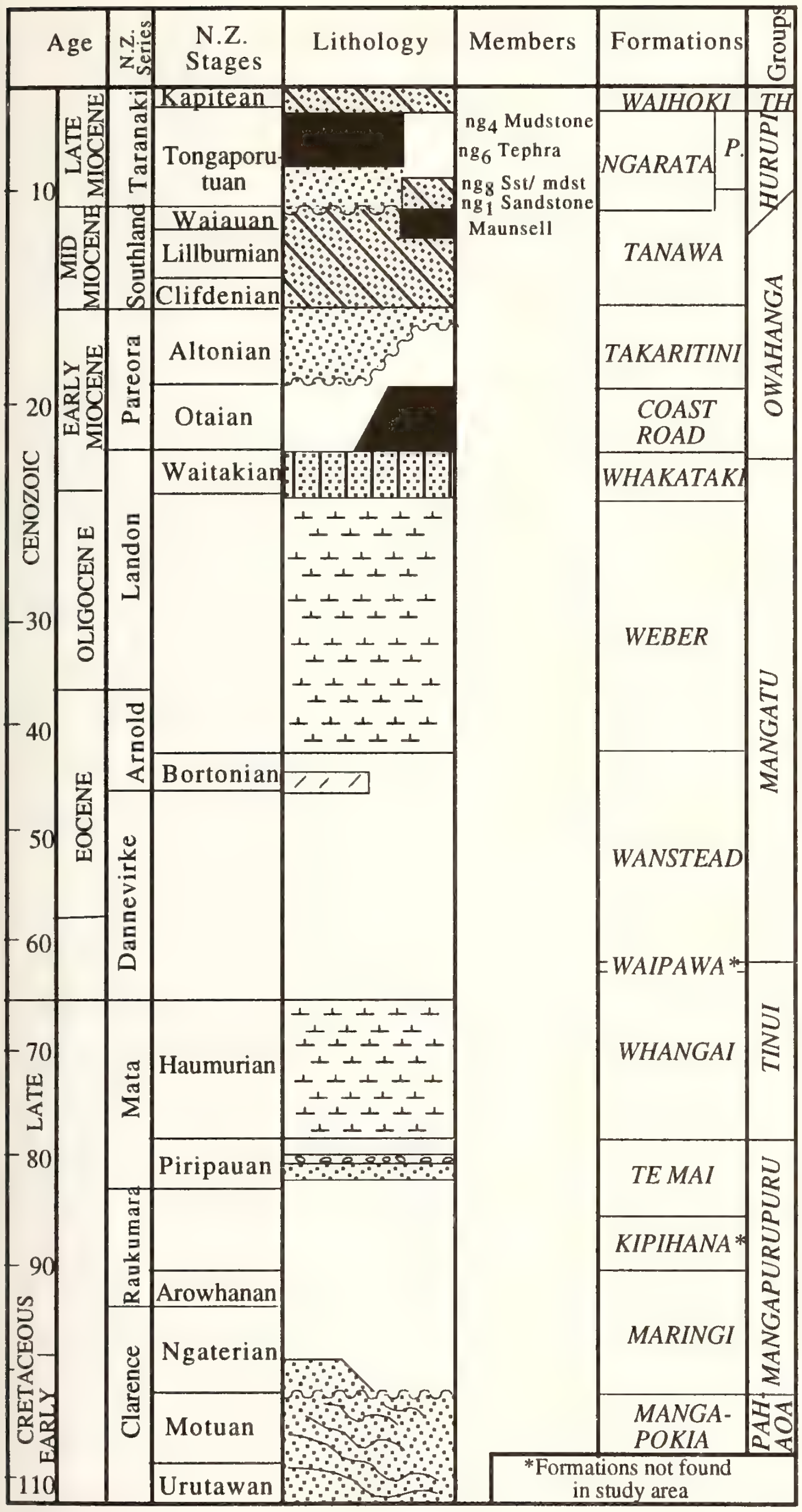


Fig. 5. Stratigraphic column of strata in the study area. TH = Te Hoe Group and P = Pakowhai Formation.

formation is likely to have been deposited in a bathyal environment.

WIG SUBGROUP
(Neef 1991b)

TE MAI FORMATION
(redefined, Neef 1991b)

Distribution: The formation crops out as a 70-75 m-wide, 0.8 km-long sliver between the Dalziell and Grassendale faults in the headwaters of Makirikiri Stream.

Description and Thickness: The formation comprises two lithofacies, a basal sandstone and an upper rudite. The sandstone, 60 m thick, is lightly indurated and locally it is carbonaceous (Fig. 6). The rudite, 75 m thick, comprises angular, subangular and subrounded clasts chiefly 10-20 mm long (max. length 0.4 m) and it is part matrix supported and part clast supported. Clasts include dacite, rhyolite, granophyre, granite, and calcareous siltstone (Johnston and Brown 1973, table 1). Also present are lightly indurated clasts, and rare fragments of *Inoceramus* sp. and a belemnite (Johnston and Brown 1973). Rare, 0.1 m-thick, fine sandstone beds are subvertical.

Age: Fossil spores/pollen indicate an early Piripauan age for strata near the base of the sandstone lithofacies (T25/f66, 633420). The belemnite *Dimotobelus lindsayi*, reported by Johnston and Brown (1973) is a Piripauan index fossil (Stevens and Speden 1978, p. 290).

Depositional Environment: The sandstone lithofacies is possibly nonmarine whereas the rudite, which contains marine molluscs, is very shallow marine. That is, the formation represents deposition at a Late Cretaceous shoreline.

TINUI GROUP
(Johnston 1975)

WHANGAI FORMATION

Distribution: The formation crops out as a 250 m-wide, 2.5 km-long sliver between Dalziell and Grassendale faults, and it is mapped locally in the east adjacent to the Tinui and Breakdown faults.

Description and Age: The formation, a rusty weathering siltstone, is siliceous and lacks macrofossils. It represents the Rakauroa Member of Moore (1988).

Depositional Environment: The forma-

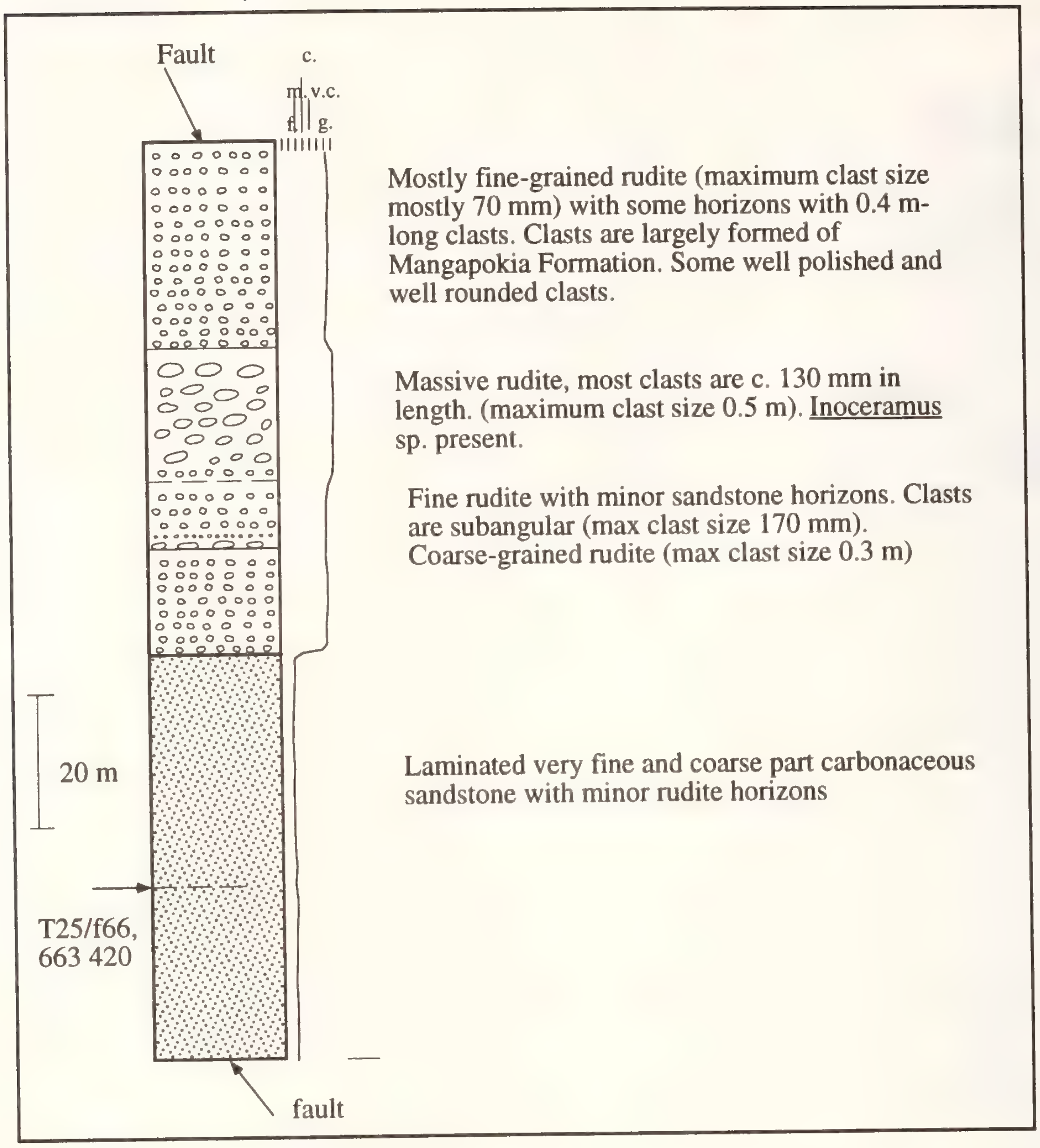


Fig. 6. Stratigraphic column of the Te Mai Formation in the headwaters of Makirikiri Stream.

tion is of bathyal aspect indicating a phase of Late Cretaceous downwarping in the Tinui district. The formation's uniformity and absence of coarse grained strata suggests a sediment-drift mode of deposition to the east of a landmass of low relief (Neef 1992b).

MANGATU GROUP
(Wellman 1959)

WANSTEAD FORMATION
(Moore *et al.* 1986)

Distribution: The formation crops out locally in the east and it is also exposed near Manawa Trig in the southwest.

Description, Thickness and Age: Because of its bentonite content, which causes slips to form, the formation is poorly exposed. Road cuts near Te Mai Station show some graded bedding. A foraminiferal sample from 600 m NNE of Manawa Trig (T25/f9948, 645425) has a Bortonian age (Johnston 1980), and the formation has a Teurian to Bortonian age range (Moore *et al.* 1986).

Environment of Deposition: The formation is bathyal (Neef 1995). The bentonite within the formation may be detrital (Moore 1988) or due to the weathering of volcanics (Ballance 1993).

WEBER FORMATION
(Johnston 1975)

Distribution: The formation crops out in the eastern part of the study area adjacent to the Tinui, Aberfoyle, and Breakdown faults.
Description and Thickness: The formation is a highly calcareous, pale grey mudstone (the limestone facies of Moore *et al.* 1986). It is at least 720 m thick (Neef 1995).
Age: The formation is Oligocene in age (Moore *et al.* 1986).
Environment of Deposition: The formation represents a widespread bathyal, impure calcareous ooze (Neef 1995) at a time when the area lay within a passive margin environment (Ballance 1993).

WHAKATAKI FORMATION
(Johnston 1975)

Distribution: The formation is mapped on the eastern part of the study area. It is well exposed near Te Mai Station and in the banks of the Pakowhai River.
Description and Thickness: The formation, which is conformable on Weber Formation, comprises well developed Bouma sequences which at Te Mai Station are 10-30 cm thick (facies C2.2 of Pickering *et al.* 1989).
Age: A Waitakian age is favoured because the overlying Coast Road Formation is Otaian in age (Neef 1995).
Environment of Deposition: Deposition was from southeast-flowing turbidity currents of normal density (Neef 1992a). Syndepositional sliding of the formation on Weber Formation near Te Mai Station suggests that the Tinui Fault was active in the Early Miocene (Neef 1995).

OWAHANGA GROUP
(Neef 1991b)

COAST ROAD FORMATION
(Neef 1991b)

Distribution: The formation is well exposed along the Tinui River at the southern margin of the study area.
Description: The formation largely comprises massive grey mudstone, and it contains a few sandstone beds, which dip moderately steeply to the southeast.
Age: Foraminifera from just south of the study area (U26/f12, 763394) are late Waitakian-Otaian in age whereas U25/f115, 760400 has an Altonian age.
Depositional Environment: Foraminifera from U25/f115 give outer shelf-upper bathyal depths of deposition. The formation was formed from hemipelagic mud.

TAKARITINI FORMATION
(Johnston 1975)

Distribution: The formation is mapped southwest of Te Mai Station at Takaritini Stream, in the Pakowhai River and the scenic Three Kings Flat Irons. It is also present but very incompletely developed between Te Mai Station and the Pakowhai River.
Basal Contact: Because the Coast Road Formation is largely absent, the formation is generally unconformable on the Whakataki Formation.
Description and Thickness: At the type section at Takaritini Stream the formation is only 140 m thick, having basal beds rich in phosphatised pebbles, echinoids, *Cucullaea* sp. and *Lentipecten hochstetteri* (Neef 1995). The formation is massive in the Pakowhai River, and ~ 350 m thick west of Rara Trig where there are erosion-resistant beds ~ 6 m thick (Neef 1995, fig. 13).
Age: The formation is Altonian in age (Neef 1995).
Depositional Environment: The formation is shelf deposited perhaps in a storm regime (Neef 1995).

TANAWA FORMATION
(redefined Neef 1991)
(Maunsell Formation, Johnston 1975)

Nomenclature and Type Section: Most of the formation comprises turbidite, mapped as Tanawa Formation, whereas mudstone (Maunsell Mudstone Member) is minor. The type section lies along the Mataikona River between U25/786446 and U25/775452.

Distribution: The formation crops out in a 1.5 - 2.5 km northeast-trending belt at the eastern margin of the study area.

Basal Contact: South of the Rahiwi Fault, and north of Pakowhai River the formation is conformable on the Takaritini Formation. Elsewhere the formation is unconformable on Weber or Whakataki formations.

Description and Thickness: Near Te Mai Station the 170 m-thick Packspur Conglomerate Member is basal (Neef 1992a, 1995). The lower two thirds of the formation is formed of sandstone-mudstone couplets of medium thickness (C2.2 facies of Pickering *et al.* 1989) (e.g. those exposed in the Mataikona River; Fig. 7). Upwards the sandstone parts of the couplets decrease in thickness (C2.3 facies of Pickering *et al.* 1989; mud turbidites, Einsele 1992, p. 215). The couplets, which have abrupt bases, show cut and fill structures and streaming lineations, and locally at their base there are invertebrate and plant fragments. Apart from the sandstone-mudstone couplets there is a sandstone-filled channel, with scattered macrofossils (along Pakowhai River at U25/778516, Neef 1992a). In a north-flowing tributary of Pakowhai River at U25/765500 there is a recumbent fold (soft sediment formed) (Fig. 8) with thanatocoenotic Mollusca: *Glycymeris* (*?Manaia*) sp.; *Polinices* cf. *intracrassus, Struthiolaria* (*Callusaria*) cf. (U25/f103, 765500). Nearby there is a pebbly thanatocoenotic shell bed with *Glycymeris* (*Manaia*) cf. *hurupiensis, Polinices* cf. *intracrassus, Struthiolaria* (*Callusaria*) cf. *spinosa* and *Penion crawfordi* (U25/f107, 764508).

Fig. 7. Uniform well developed C2.2 lithofacies (turbidite) in the mid part of the Tanawa Formation, at Mataikona River (U25/778450). Backpack near bottom right gives scale.

The formation is 1.8 km thick along the axis of the Tanawa Syncline (cross section A-B, Fig. 3).

Maunsell Mudstone Member
(Neef 1991b)

Distribution: The member forms a ~ 800 m-wide, NNE-trending belt west of the Tinui River.

Description and Thickness: The member, 400 m thick near Rahui Station, comprises massive mudstone with common 50 mm thick very fine sandstone beds.

Fig. 8. Slumped C2.2 lithofacies (turbidites) in a tributary of the Pakowhai River at U25/765500. Backpack near centre gives scale.

Age of the Formation: Foraminifera from near the base of the Tanawa Formation (U25/f117, 784468; U25/f128, 783468) give late Lillburnian - Waiauan ages whereas the Takaritini Formation, which lies not far below, is Altonian in age. The base of the Maunsell Member has a Waiauan age (U25/f129, 772466) whereas its upper part has a Waiauan - lower Tongaporutuan age (U25/f88, 742422).

Depositional Environment: The formation was deposited largely from south-southeast flowing, low-velocity turbidity currents derived from west of the Waioakura Horst which lies 4 km to the NNE of the northern margin of the study area (Neef 1992a, Neef in press). The Packspur Conglomerate Member, however, was interpreted to represent the fill of a small westward-trending submarine canyon (Neef 1992a). Foraminifera indicate that much of the Tanawa Formation was deposited at mid-upper bathyal depths (i.e. ~ 1000 m) (U25/f117;U25/f128).

The thanatocoenotic shell beds (U25/f103, f107) lie close to the Mt York Fault and the shells forming the shell bed may be derived from a local submarine high along the fault rather than from the Owahanga Block to the east. Asymmetry of the slump folds indicates a palaeoslope to the south (Fig. 8).

The Maunsell Mudstone Member was also deposited at mid-upper bathyal depths (U25/f129; U25/f76) whereas sample U25/f88 has a mid bathyal depth of deposition. Part of the member originated from distal mud-transporting turbidity currents (from the presence of thin sandstone beds), and part originated from hemipelagic mud. Perhaps syndepositional folding of the Tanawa Syncline caused the limbs of the syncline (especially the east limb) to rise relative to the axis causing turbidity currents to be channelled along the axis of the syncline.

South of Mt York the upper part of the formation wedges out into the Maunsell Member.

	f50	f51	f52	f53
?Poroleda sp.	X			
Lentipecten hochstetteri			X	
Anomia trigonopis			X	
Eumarcia (Atmarcia) thomsoni				X
Kuia macdowelli			X	
?K. macdowelli	X			
Eucrassatella ?ampla			X	
Dosinia (*Kereia*) cf. *cottoni*			X	
"Pholadomya" cf. *warreni*	X			
Zeacolpus (s.str.) *taranakiensis*	X			
Struthiolaria (s. str.) *praenuntia*				X
S. (Callusaria) ?spinosa				X
S. (*C.*) sp.			X	
Zegalareus sp.			X	
Polinices intracrassus				X
P. cf. *intracrassus*		X		
P. sp.			X	
Friginata vaughani			X	
?Cominella sp.			X	
Alcithoe cf. *dilatata*			x	
Austrotoma cf. *nervosa*			X	
Dentalium cf. *solidum*			X	

Sample	Grid Ref.	Locality
T25/f50	T25/658 455	Forestry Track
T25/f51	T25/659 457	Forestry Track
T25/f52	T25/665 452	Creek
T25/f53	T25/623 449	Forestry Track

Table 1. Macrofossil list ng_1 Sandstone Member, Ngarata Formation. (Identifications by A.G. Beu.)

HURUPI GROUP
(Johnston 1975)

NGARATA FORMATION
(Neef 1974)

The Ngarata Formation comprises the following members: ng_1 Sandstone, ng_2 Conglomerate, ng_3 Siltstone, ng_4 Mudstone, ng_5 Tephra (Neef 1974). Subsequently the ng_6 Tephra and the ng_7 Rudite have been described in the northern part of the Tawhero Basin (Neef in press) and the ng_8 Sandstone-Mudstone member is described here.

Distribution: The formation forms a 4.5 to 7.5 km wide, 15 km long, north-trending belt at the western margin of the study area. Mudstone developed west of the Waihoki Fault in Makoura Stream is also attributed to Ngarata Formation.

Basal Contact: The formation is unconformable on the Mangapokia Formation of the Pahaoa Group.
Description and Thickness:

ng_1 Sandstone Member

The member, pale grey N6 or N7 in colour, comprises massive, moderately well sorted, fine and very-fine grained sandstone. Surprisingly, sedimentary structures including bedding are rare and invariably it is difficult, or impossible, to delineate bedding in the field or on aerial photographs. Scattered shells and cemented shell beds are present locally, especially in the west (Table 1) and *Ophiomorpha* sp. ichnofossils (commonly 15-25 mm in diameter) are common. Pebbles are rare but small mud clasts are more common. Gas from the Annedale gas vents (Johnston 1980, p. 48) probably originates from organic material trapped within the member and the vent's location, between two northeast-trending faults, is like that of the Owahanga gas vents (Neef 1995), indicating that they lie along a NNW-trending joint parallel to a thrust fault.

The member is ~ 600 m and 950 m thick south of the Grassendale Fault and between the Blue Gum and Manawa faults respectively, whereas it is only 350 m thick in the north (Section A-B, Fig. 3).

ng_4 Mudstone Member

The massive, lightly indurated mudstone (E1.1 facies of Pickering *et al.* 1989) is grey N6 or N7 in colour and it lacks macrofossils. It contains rare greensand beds. One in the uppermost part of the member has a strike length of at least 300 m. In Woody Gully Stream and at T25/695467 it contains pebbles. A clastic dike-sill complex crops out in Woody Gully Stream (Neef 1991a). Another clastic dike, having a similar strike to the one in Woody Gully Stream, crops out in Blue Gum Stream at T25/685462. It dips to the northwest at 73° and it is 60 mm thick and comprises shells and greensand.

In the north in a tributary of Makoura Stream (between U25/721525 and U25/723525) there is a 90 m thick sequence near the top of the member that comprises, at its base, macrofossil-rich coarse sandy debris-flow deposits (max. thickness 0.3 m) interbedded with mudstone beds 0.3 - 2 m thick (Neef in prep.) At the top of the sequence there are five macrofossil-rich bouldery debris-flow deposits 2-4 m thick (max. boulder length 0.65 m), which alternate with mudstone beds 6-10 m thick. Macrofossils, displayed in the garden of Waitawhiti Station, are from debris-flow deposits near Island Trig (U25/723532).

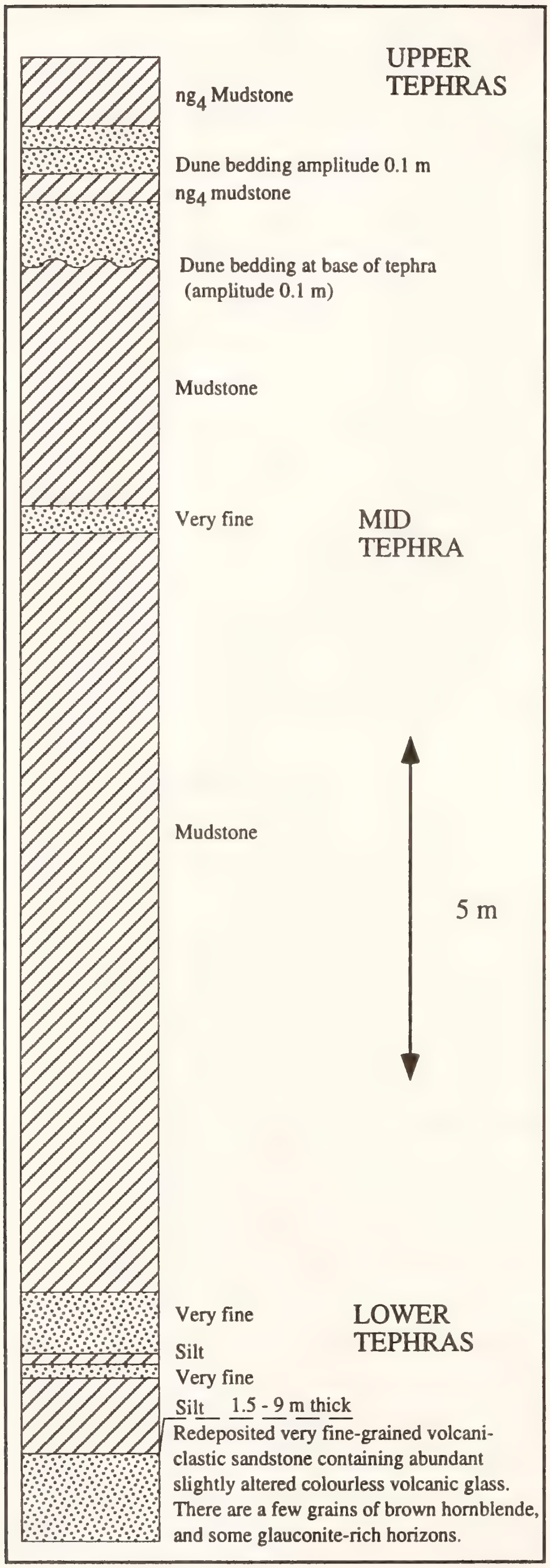
The member, fully developed, is ~ 850 m thick between Manawa and Blue Gum faults, and ~ 270 m thick in Section A-B (Fig. 3).

ng_6 Tephra Member

The member crops out in the lower part of the ng_4 Mudstone Member. It comprises six tephra beds that alternate with mudstone beds. The member is best exposed at the type section (a hillside south of Peninsula Station at T25/677404) (Fig. 9). The tephras are very pale grey and fine-grained and together they form a minor ridge in the southwest of the study area. The tephra member is traced northwards to Whareama River (T25/674412), where a tephra bed is 2.2 m thick, and then 1 km to the NNW to the Grassendale Fault. North of the fault a tephra bed overlies several greensand beds. The member also crops out in Blue Gum Stream (T25/671468) where the ?lower tephra is 5 m thick and very pale grey in colour, and 3 km to the NNW at T25/668498 where it is 1 m thick.

ng_8 Sandstone and Mudstone Member

Couplets of sandstone-mudstone commonly 0.2 - 0.3 m thick (max. thickness 1 m) crop out between the Grassendale and Manawa faults



(where the member is ~ 200 m thick) and between Blue Gum and Wairiri faults where the member is ~ 100 m thick. Locally the sandstone parts are laminated at their bases.

Age: Macrofossils from the central part of the ng_1 Sandstone Member (T25/f52, 665452) (Table 1) have an early Tongaporutuan age and macrofossils from T25/f50, 658455 which underlies T25/f52, are probably Tongaporutuan. A sample from the upper part of the ng_4 Mudstone Member T25/f49, 697476) also has a Tongaporutuan age. Surprisingly a Kapitean index fossil, *Austrofusus coerulescens* (T25/f6434, 680481, found by M. Ongley) (Johnston 1980, p. 36) was collected ~ 150 m below the base of the Waihoki Formation at a locality below where Tongaporutuan microfaunas are known (e.g. T25/f49). This anomalous occurrence could be based on a misidentification, or, perhaps, the fossil was not in place where it was collected.

Depositional Environment: Absence of the ng_2 Conglomerate Member indicates that during the early part of the formation's deposition there was little local marine erosion of the underlying Mangapokia Formation and that the area was generally one across which sand was being transported. Because of the rarity of sedimentary structures it is unclear if the ng_1 Sandstone Member was deposited within a tidal or a storm dominated environment. Depth of deposition was probably mid neritic and the massive nature of the member was probably due to substantial bioturbation (much of it due to the activity of ghost shrimps). The length of the ghost shrimps can be estimated from the diameter of their burrows (15-20 mm) (Neef 1978). These data suggest that the ghost shrimps that formed the burrows

Fig. 9. Composite section in the ng_6 Tephra Member south of Peninsula Station at T25/677404.

were the ancestors of the present day, mid to outer neritic-indicating *Ctenocheles maorianus* or *Axiopsis* n. sp. (Neef 1978). The thin development of ng_1 Sandstone between the Grassendale and Manawa faults is due to syndepositional faulting causing local uplift there. Absence of ng_3 Siltstone Member indicates relatively sudden downwarping. Foraminifera from basal part of the ng_4 Mudstone Member were deposited at outer shelf - upper bathyal depths and the ng_8 Sandstone-Mudstone Member is also thought to have been deposited in this depth range. Subsequently the mid-upper parts of the ng_4 Mudstone Member were deposited at mid - upper bathyal depths (e.g. T25/f105, 694471) from suspension. Dune bedding at the base of the upper tephra of the ng_6 Tephra Member indicates high flow regime transport prior to the deposition of the tephra. The associated greensand beds are also most likely to have been redeposited.

The fossil-rich debris-flow deposits of Makoura Stream, lying 200-400 m west of the Waihoki Fault are like those described from Tongaporutuan strata adjacent to the fault at Huia Road (7.5 km to the NNE) (Neef in prep.), and they also resemble Jurassic debris-flow deposits near the Helmsdale Fault of Scotland (Wignall and Pickering 1993). Like the deposits at Huia Road they indicate that a Tongaporutuan fault sliver lay along the Waihoki Fault and that it reached the neritic zone, forming an environment favourable to molluscs. Evidence of Tongaporutuan dextral and thrust faulting is from the clastic dike in Woody Gully Stream which has vertical and horizontal slicklines at its margin (Neef 1991a).

PAKOWHAI FORMATION

(Neef 1991b)

Distribution: The formation forms a 1-6 km wide north-trending belt east of Tawhero Syncline.

Basal Contact: North of Pakowhai River the formation is conformable on Tanawa Formation whereas south of the river the basal beds of the formation are faulted out by the Mt York Fault. Near Tanawa Trig and to its south the formation overlies the Maunsell Member.

Description and Thickness: Commonly at the base of the formation lies a massive 15 m-thick seismoturbidite bed (Neef 1992a). The lower part of the formation is formed of sandstone-mudstone couplets (turbidites) whereas its upper part largely comprises mudstone with minor sandstone beds (especially in Wingate Stream).

In the Pakowhai Gorge the lower turbidite part of the formation (~ 600 m thick) comprises mudstone-sandstone couplets of C2.1 facies of Pickering *et al.* (1989). Overlying strata, largely mudstone (see Section A-B), are ~ 480 m thick. At the southern margin of the area the turbidite part of the formation wedges out. An 80 mm-thick tephra bed in the lower part of the mudstone part of the formation is exposed in a cliff along Makoura Stream at U25/743533.

Age: The upper part of the underlying Tanawa Formation is early Tongaporutuan in age (U25/f76, 746469) and the upper part of the Pakowhai Formation is also Tongaporutuan (U25/f41, 725502) showing that the formation is entirely Tongaporutuan in age.

Depositional Environment: The basal seismoturbidite was deposited from a rapidly flowing, highly concentrated, tephra-rich turbidity current (Neef 1992a). The overlying turbidites have Bouma sequences which indicate deposition from turbidity currents of normal density that were deposited at mid-upper bathyal depths (Neef 1992a). Many flute and groove casts at the base of the sequences indicate southward flow and an origin from north of the Waihoki Fault near Waihoki Settlement (Neef 1992a). That is

the formation was deposited, proximally, from a ramp environment (Neef 1992a) rather than from a fan environment. Because turbidite flow was parallel to the axis of the Waihoki Syncline it is likely that the fold was forming in early Tongaporutuan time (Neef 1992a). The lower turbidite part of the formation wedges out at the southern margin of the study area indicating that turbidite flow there was up an incline, that caused flows to decelerate. It is unclear why turbidite deposition ceased suddenly. Perhaps sediment derived from the Mangatuna High (near Pongaroa, Ridd 1967) was abruptly directed elsewhere.

The middle and upper parts of the formation are largely formed of mudstone deposited from suspension at bathyal depths (e.g. mid-upper bathyal, U25/f41). Common sandstone beds in Wingate Stream and a virtual absence of sandstone beds in Makoura Stream, suggest that sand derivation was from the east.

TE HOE GROUP
(Neef 1974)
WAIHOKI FORMATION
(Johnston 1975)
Waihoki Series (Ongley 1935)

Type Section: The strata exposed at Gunpowder in the headwaters of the Whareama River between T25/696463 and U25/706463 represent the type section.

Distribution: The formation crops out as a 2.5 - 4.5 km-wide, 15 km-long, north-trending belt in the centre of the area.

Basal Contact: Commonly the base of the formation is poorly exposed; however in Woody Gully Stream exposures show a conformable contact (Fig. 10).

Fig. 10. Stratigraphic contact between ng_4 Mudstone Member and the Waihoki Formation in Woody Gully Stream at T25/694470. The upper concretion ~ 2 m long lies at the base of the Waihoki Formation and there is some minor bedding in the ng4 Mudstone Member.

Description and Thickness: Much of the formation comprises thick sandstone-mudstone couplets (Facies C2.1 of Pickering *et al.* 1989). However, locally thinner couplets are present (Facies C2.2 of Pickering *et al.* 1989). Near Middle Hill Trig the base of the formation is marked by a 42 m-thick sandstone bed, and a thick basal sandstone is known south of the study area at Ekenui Stream (Johnston 1980, p. 34). Surprisingly the sandstone parts of the couplets along the west limb of the syncline are much thinner than those along the east limb (Johnston

Fig. 11. Sixty metre exposure of Lower Waihoki Formation in the southernmost part of the study ara at U25/701414. Note that turbidite is generally C2.2 lithofacies. C2.1 lithofacies lies in the centre.

1980, p. 35). Johnston also found that the basal part of the formation has a considerable reworked tephric component. In Wingate Stream the upper part of the underlying Pakowhai Formation has several thick sandstone-mudstone couplets and the basal contact of the formation is less certain there.

On the west limb of the Tawhero Syncline the lower part of the formation is well exposed at U25/701414 (Fig. 11), where the thickest sandstone part of the couplets is 2 m thick and has a very irregular base, above which there are 100 mm-long mudstone clasts. Most of the mudstone parts of the couplets are pale grey (N7) whereas two mudstone beds are slightly darker in colour.

The formation is excellently exposed at Gunpowder (Neef 1992a, fig. 18) where alternating units, 5-15 m thick, have thick or thin sandstone parts. Commonly the sandstone parts of the couplets are poorly graded, massive and laminated (Fig. 12).

The formation, which is incompletely developed because younger beds are absent, is at least 425 m thick (see Section A-B).

Age: Foraminifera from Gunpowder U25/f83, 706463 have a late Tongaporutuan - early Kapitean age, and foraminifera from north of the study area suggest that the base of the formation is earliest Kapitean in age (Neef in press).

Depositional Environment: Foraminifera from U25/f83 indicate an outer shelf environment of deposition. Many features of the couplets such as their abrupt bases, however, indicate upper bathyal turbidite deposition. Much of the sediment, partly derived from redeposited tephras, originated east of the Tinui Fault (Neef 1992, fig. 9). The formation was deposited from highly concentrated flows like those described by Pickering *et al.* (1989). The abrupt thinning of the sandstone parts of the couplets westwards indicates deceleration of the turbidity

Fig. 12. Six metre exposure of C2.1 lithofacies in the upper part of the Waihoki Formation in the headwaters of the Whareama River at U25/701445. Note well developed lamination in the sandstone parts of the couplets.

currents - presumably because they were flowing up a slope.

QUATERNARY

At about 1.2 Ma the forearc rose out of the sea (Neef in prep. and others) due to an underplating event of the forearc (Walcott 1987). Quaternary erosion surfaces are recognised at 600 m (the Puketoi Surface of Neef 1967) which is probably 1.2 Ma and at 300 m (the Hinemoa Surface of Neef 1967) which is probably 0.6 Ma (Neef in prep.). In northwest Wairarapa two fluvial styles are known during the Late Quaternary. During cold periods rivers aggraded their courses to build terrace deposits (which invariably are capped by loess and occasionally with airfall tephras) whereas during warm periods rivers incised their beds and removed part of the previously deposited gravel (Vella *et al.* 1988).

In some parts of the study area there is evidence of substantial incision of the beds of rivers. For example adjacent to the gorge of the Pakowhai River there are narrow terrace remnants ~ 95 m higher in elevation than the river bed. North of the gorge a terrace at an elevation of 180-200 m grades imperceptibly into adjacent hillsides indicating formation during the last stadial of the last glaciation, or ~ 10-12 k.yr., (Vella *et al.* 1988). Locally, in the headwaters of the Pakowhai River, terraces adjacent to the river are a few tens of metres higher in elevation than the bed of the river, indicating they are late Holocene in age and that there has been rapid uplift there. Also there are narrow terrace remnants, 40 to 50 m higher than the bed of the Whareama River, which grade into adjacent hillsides indicating that they too are 10 to 12 k.yr. in age.

Solifluction deposits

Solifluction deposits, commonly several metres thick and comprising 50-150 mm-

long fragments, mantle many of the steeper hillsides. The deposits are also likely to have formed ~ 10-12 K.yr. ago.

Slips

Six large slips are known on the outcrop of the Waihoki Formation (Fig. 2). They are due slip at the base of the sandstones after heavy rain (Johnston 1980). Also important in slip formation are the northerly- and southerly-dipping normal faults (they form discontinuities and thus enhance down-slope sliding).

Taupo Pumice

Adjacent to a track a T25/624405, airfall pumice 0.2 m thick, derived from the Lake Taupo area in 186 AD (Walker 1980), overlies a 3 m thick solifluction deposit and is overlain by top soil ~ 0.5 m thick.

STRUCTURE

The structure of the study area is largely represented by widely spaced NE- or NNE-trending faults and folds. The Tinui Fault Complex in the east and the Waihoki Fault in the west are the most important structures. Between them lies the southern part of the Tawhero Basin. Many of the north-east-trending faults of the study area are thought to be also inclined to the west at ~ 70°. However the Waihoki and Tinui Faults have histories of dextral movements and they are thought to dip more steeply (~ 85° to the west). Late Quaternary fault traces are absent. There are three structurally complex areas: on the forearc ridge in the southwest corner of the study area near Manawa Trig; in the Tawhero Basin near Rahiwi Station; and in the southeast where the Tinui Fault Complex is present. As in the northern Tawhero Basin much of the structure, especially the faults, is considered to have formed before latest Tongaporutuan time.

Southern Tawhero Basin

Structure is considered to be like that of the northern Tawhero Basin which formed during Miocene dextral transpression (Neef in press) (term coined by Sanderson and Marchini 1984). In the southeast the Tinui Fault Complex comprises the Tinui, Aberfoyle and Rahui faults. A small fault subparallel to the Rahui Fault at U25/755423 dips 84° at 163 and displays almost horizontal slickenlines which are consistent with dextral movements on the Tinui Fault Complex. About 5 km north of Te Mai Station the Tinui Fault Complex diverges NE and the eastern boundary of the study area is marked by the Breakdown Fault. The western margin of the Tawhero Basin is delineated by the Waihoki Fault, which became inactive in latest Tongaporutuan time, and is covered by the Waihoki Formation. South of the study area the Marangi Fault of Johnston (1975) is probably an extension of the Waihoki Fault.

Utilising the Sanderson and Marchini (1984) model, the eastern part of the Mt York Fault and the Tanawa Hutt Fault are dextral synthetic faults, whereas the Rahiwi Fault is a sinistral synthetic fault. It has a 0.12-wide fault zone that dips 85° to southwest at U25/739451. The Wingate, Breakdown and southern part of the Mt York faults are considered to be thrust faults —the overturned seismoturbidite bed of the Pakowhai Formation (at U25/749498) (adjacent to the Mt York Fault) is also consistent with a thrust origin for the NNE-trending part of the fault.

Forearc ridge (lies west of the Waihoki Fault)
The northeast-trending Grassendale, Dalziel, Manawa, Blue Gum and Wairiri faults are considered to be dextral synthetic faults (deduced from the Sanderson and Marchini 1984 model). The northwest trending fault lying north of the Tiraumea Road may be a sinistral synthetic fault whereas the NNW-trending fault west of Annedale Station is thought to be a thrust fault. The Spring Hill Anticline was growing during Tongaporutuan and Kapitean time (Neef in press) (Fig. 4).

Tawero Syncline (Ongley 1935)
The north-trending gentle symmetrical Tawhero Syncline is a major feature of the area. It partly overlies an inactive Waihoki Fault and formed during Plio-Pleistocene time. Its eastern margin shows minor faults (which trend SWS in the south and north-east in the north). Exposures near the axis of the syncline show common minor faults that dip northerly or southerly at ~ 60°.

GEOLOGICAL HISTORY

The Mangapokia Formation of Early Cretaceous age was deposited in bathyal seas. Shortly after deposition, it was deformed during an inter-Motuan orogeny (Moore and Speden 1984). Following the orogeny, bathyal Maringi Formation of the Makatoke Stream Subgroup was deposited. After a further period of deformation the near shore conglomerate-sandstone beds of the Te Mai Formation (lower Wig Subgroup) were deposited during Piripauan time when there was continued uplift in the hinterland. The deposition of the bathyal Whangai Formation, of Late Cretaceous age, indicates an absence of mountains/hills in the hinterland and the presence of an offshore boundary current (Neef 1995).

The bentonitic Wanstead Formation is calcareous (sourced from foraminifera and nannofossils, Moore 1988), perhaps due to the northwest drift of the Pacific plate (Ballance 1993). The highly calcareous Weber Formation formed at a time when the whole of New Zealand was submerged (Ballance 1993). The Whakataki Formation, partly sourced from Mesozoic greywacke (Korsch *et al.* 1993), represents a period when there was uplift in the west - perhaps the Waihoki Fault represents the western margin of the depositional area (Neef in press). The area of the trench slope break, however, had not begun to rise.

Owahanga Group
Bathyal mudstone of the Coast Road Formation crops out locally within the Tinui Fault Complex but it is absent entirely west of the complex (Neef 1995). This indicates that the fault was active during Otaian time. At ~ 7.5 Ma, in late Altonian time, subduction of the underlying Pacific plate became oblique, causing, in the Tawhero Basin, alternating periods of tectonics due to subduction or to dextral transpression (Neef in press). At this time the trench slope break and the forearc ridge were progressively uplifted, Late Cretaceous and Paleogene strata on the ridge were eroded and the derived sediment were deposited in the growing Tawhero Basin. Considerable activity along the Tinui Fault complex during Altonian time is indicated by the great variations of thickness of the Takaritini Formation and locally its complete absence. The Rahiwi Fault was active

in early Lillburnian time because the fault separates Takaritini and Whakataki formations south of the fault from areas north of the fault where the Takarititi and Whakataki formations are absent and the Tanawa Formation is unconformable on Weber Formation (Neef 1995).

In Lillburnian and Waiauan time the bathyal Tanawa Formation was deposited largely from southward-flowing, low-velocity turbidity currents (Neef 1992a). Syndepositional slumping near the Mt York Fault suggests that the fault was active in late Lillburnian time. In early Waiauan time early growth of the Tanawa Syncline caused turbidity currents to be channelled southwards along the synclinal axis and mud (Maunsell Mudstone Member) to be deposited on its eastern limb.

Hurupi Group

In early Tongaporutuan time there were widespread unconformities in the northern Tawhero Basin (Neef in press) and the forearc ridge was downwarped more or less at the same rate as downwarping in the Tawhero Basin. Thus the Ngarata Formation is widespread in northern Wairarapa (Fig. 4). The ng_1 Sandstone Member of the Ngarata Formation was deposited within a neritic environment. Sand was generally transported northwards by longshore drift (Neef in press). Especially thin sequences of the member between the Grassendale and Manawa faults indicate syndepositional uplift of the intervening block. The ng_8 Sandstone-Mudstone Member may represent deposition from shallow-water turbidity currents. The turbidite part of the bathyal Pakowhai Formation was deposited by southflowing turbidity currents (Neef 1992a). Almost as suddenly as it commenced, deposition of thick turbidite ceased. The upper part of the formation was formed of hemipelagic mud. Some sandstone beds, especially those in Wingate Stream, were probably derived from the east.

West of the Waihoki Fault the ng_4 Mudstone Member was deposited from suspension in bathyal seas (like the seas of southern Wairarapa, Wells 1989). Tephras in the ng_4 Mudstone Member are rare and they were derived from volcanoes present in the southern part of the Coromandel Peninsula (Kear 1994). The tephra in Blue Gum Creek is not widespread, indicating that it represents the fill of a slope gully. Association of the ng_6 Tephra Member with greensand beds (especially adjacent to the Grassendale Fault) indicates the glauconite of these greensand beds originated on nearby submarine highs.

In the north, in the headwaters of Makoura Stream, macrofossil-rich, debrisflow deposits resemble debris-flow deposits adjacent to the Helmsdale Fault of Scotland (Wignall and Pickering 1993). They formed due to syndepositional faulting along the Waihoki Fault (like that described 7.5 km to the NNE at Huia Road; Neef in prep.). It is probable that the fault was active throughout much of the Tongaporutuan. Vertical and horizontal slickenlines at the margin of the clastic dike near Annedale (Neef 1991a) indicate that seismicity at ~ 6 Ma was as it is today (~ 100 yr. long periods of dextral faulting alternating with ~ 100 yr. long periods of compression, due to the subduction process, Walcott 1978).

Te Hoe Group

The bathyal Waihoki Formation formed from high-density turbidity currents flowing westwards from east of the Tinui Fault (Neef 1992a). The turbidites of the formation were ponded against a growing Spring Hill Anticline (Neef 1992a) and they represent the final fill of the Tawhero Basin.

Plio-Pleistocene

Bedding in the Waihoki Formation in the east limb of the Tawhero Syncline near Tawhero Station is two-thirds of the value to the bedding on the underlying Pakowhai Formation indicating that tilt rates there have doubled since the early Pliocene.

Holocene

In early Holocene time rivers were able to incise their beds but there was little downstream migration of the meander belts. This is consistent with accelerating uplift rate - and local uplift rates of > 4 mm/yr.

SUMMARY

1. During the period 24 - 6 Ma the Tawhero Basin was bounded by the active Tinui Fault Complex and the Waihoki Fault. The basin formed as a result of subduction tectonics but it was also deformed after ~ 17.5 Ma by syndepositional dextral transpression.
2. During basin formation the bounding forearc ridge and the trench slope break were uplifted and eroded (especially the Late Cretaceous and Paleogene stratal cover of the forearc ridge). At 10.5 Ma the forearc ridge was downwarped at about the same rate as the Tawhero Basin and sedimentation on the forearc was widespread.
3. At 6 Ma the Tawhero Basin and the forearc ridge were fused and there was considerable uplift of the trench slope break area from which the turbiditic Waihoki Formation was derived.
4. There is an absence of Late Quaternary faulting in the study area whereas Holocene uplift rates are high (possibly ~ 4 mm/yr).

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Nuclear Propulsion for Submarines and Surface Vessels A Review

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NUCLEAR PROPULSION

Today more than three hundred ships are propelled by nuclear plants. They all use pressurised water reactors, and are either:

- Naval Surface Ships
- or Submarines

The first vessel of any kind to use nuclear power was a submarine, the *USN Nautilus*. At the time of her launch, she was the world's largest submarine. Almost exactly one year later she flashed an historic message from Long Island Sound, a stretch of water off the eastern coast of the USA: *"Under way on nuclear power"*. In the years that followed, *Nautilus* and her successors rapidly demonstrated the tremendous advantages that nuclear power gives a submarine. Forty years later more than five hundred reactors are in service around the world on board three hundred and fifty American, British, Russian, Chinese and French vessels.

NUCLEAR PROPULSION FOR SURFACE SHIPS

In the sixties it looked that nuclear propulsion could also apply to merchant ships. The 10,000 tonne freighter *Savannah* in the US, and a German ore ship the *Otto Hahn* of equivalent capacity were commissioned in 1962 and 1968 respectively. Drawings for their successors have since been kept in their filing cabinets. Their main problem was obtaining free access to harbours in a number of countries but there were others, such as flags of convenience.

A nuclear propulsion assembly is voluminous and dense, partly on account of the heavy radiological protection. On board a submarine, this is acceptable because it is a very compact vessel not designed to carry any commercial freight. Its weight, submerged, is equal to the lifting force with a density of 1, which is about the same for the nuclear reactor assembly proper. The weight and width of the reactor determine the submarine's overall size and the diameter of the hull.

It is far different for a surface ship with a density three to five times less than when unladen. Her size has therefore to take into consideration the extra weight of the nuclear reactor and its heavy metal shielding in order to make the ship commercially economical.

Designed as the first frigate with nuclear propulsion, the *USS Longbeach* was eventually commissioned as a cruiser. Since then all surface ships in the US Navy, excluding

aircraft carriers, are above 9,000 tonnes. This impact of weight on size is reduced as the size of the ship increases. This is the case for aircraft carriers.

The cost of a conventional submarine is approximately A$250,000/$m^3$. The cost of a frigate with conventional propulsion is at least three times less. The cost of the nuclear plant alone is also A$250,000/$m^3$, and therefore makes the cost of a nuclear plant a heavy burden on surface ships

Another factor increasing costs is the high quality of parts and sophisticated fabrication procedures of all components of the nuclear installation required to ensure adequate safety. Costs are not so different for a submarine because high technology components are necessary throughout anyway. A merchant ship is of much simpler design.

Finally the maintenance and logistic support required for a nuclear merchant ship are out of proportion when compared with the support required for a conventional one.

Where Navy ships are concerned, cost is not always the dominant factor, especially not when a country has the means to afford them. Nuclear propulsion ensures a greater mobility and endurance and this particularly applies to an aircraft carrier and her escort which often have to operate at high speed when planes are taking off or landing. These are more decisive factors than costs.

An often useful advantage of nuclear propulsion for aircraft carriers or cruisers is that it eliminates the need for funnels that induce air turbulence, which in turn affects the operation of aeroplanes and helicopters.

A surface ship is, of course, more exposed to missiles than a submarine. Nuclear propulsion greatly improves speed and mobility for an aircraft carrier and her escort but it does not eliminate vulnerability, far from it. Above a certain size a surface ship has to be designed and constructed to take blows and survive. This requires very heavy protection of the nuclear plant not only for major conflicts but also for intervention in any areas likely to be hostile.

The US Navy has made a choice which few other countries can afford. Its aircraft carriers are the largest by far and most expensive because they were designed to carry aeroplanes of all types and aptitudes whatever the flying condition. The cost of nuclear propulsion is only one item among many others of an extraordinarily high budget.

Aircraft carriers are deployed with escorts well equipped with anti-aircraft, anti-surface and anti-submarine warfare weaponry and also with detection devices, which make hostile aggression unlikely to succeed. There remain the problems of defence against ballistic missiles with or without nuclear warheads. Carriers are sometimes criticised in the USA because of their price and their key importance which makes them prime targets for hostile fleets.

In northern Russia, with its exceptional winter conditions, nuclear propulsion looks successful for ice-breakers which, thanks to nuclear power, can survive isolated from the rest of the world for long times. The costs are then irrelevant. The Russians are also designing cargo ships for use in ice fields. Spending a winter in the Arctic certainly justifies different considerations. As for their navy the Russians envisage surface ships with a relatively small reactor for cruising and supplying power on board, and additional oil burners to boost the steam pressure for higher speed.

A Japanese project to build a nuclear powered commercial vessel about twenty years ago had to be abandoned because of strong anti-nuclear public opinion. Nevertheless the Japanese still maintain a research and development programme for the use of nuclear propulsion for surface ships.

NUCLEAR SUBMARINES

Nuclear Submarines are in service in the navies of the USA, the UK, Russia, China and France, while India has one under construction. There are two types of nuclear submarines: the attack vessel known as SSN (Submarine Ship Nuclear) (Fig. 1) and the missile-carrying submarine or SSBN (Submarine Ship Ballistic Nuclear) (Fig. 2). The former is designed to attack and destroy other submarines and enemy vessels. The SSBN is a frightening weapon, its role being to serve as a platform for nuclear missiles, which is hidden in the depths of the ocean. The world's SSBN forces threaten retaliation to any country that makes first use of nuclear weapons, a threat designed to prevent the outbreak of war. Threat of nuclear retaliation very likely has prevented nuclear war for half a century.

Whenever a submarine is to operate far from base and has to cover a vast patrol zone for periods of months or longer, the nuclear submarine is the only capable weapon. It has almost total independence far away from base, which is not the case for a conventional submarine. No alternative means of propulsion can compete against nuclear propulsion for oceanic submarines. Chemical, air independent propulsion (AIP) fuel systems, eg. using hydrogen gas, could be the means to improving the acoustic discretion of coastal patrol submarines which do not require great mobility. However, this cannot apply to oceanic patrols, because of constraints imposed by the storage requirements of the hydrogen or other chemical fuels on board.

In 1958 *Nautilus* passed across the North Pole, sailing deep beneath the extremely thick ice cap in that hostile region, so demonstrating that there was no ocean in the world a nuclear submarine could not command.

Operating nuclear submarines is claimed to be excessively costly, particularly by detractors. The investment is indeed substantial but nuclear energy allows the production of much larger, highly versatile and very fast vessels. The cost is a consequence of high performance requirements, and not exclusively due to the cost of nuclear propulsion. Performance levels possible with a nuclear plant cannot be achieved by any other method. No one can win the Grand Prix without a Formula 1 design.

If a country has already invested in a nuclear industry or received assistance from a friendly country, it becomes possible to develop a submarine fleet at an acceptable cost. Whatever the choice, cost and efficiency have to be compared over the whole life of submarines. From this viewpoint, it is definitely in favour of nuclear power because a conventional submarine equipped with sophisticated weapon systems will never have the mobility and invulnerability matching such an investment. This means that the choice of nuclear propulsion for oceanic missions cannot be contested, provided of course that the country concerned can afford it.

Nuclear propulsion is the only technology allowing a submarine to remain submerged and silent for a long time. Conventional submarines run on batteries which have to be recharged using noisy diesel engines. At a speed of 2 or 3 knots they can operate for several days prior to recharging but at 20 knots batteries will not last more than one hour. A nuclear submarine can run at more than 25 knots for the whole mission. Some American or Russian submarines are capable of a submerged speed of more than 50 knots at depths down to 600m.

Up to 1995, nuclear powered naval ships had covered more than 100 million nautical miles accumulating more than 4,600 reactor years of operation and have never experienced a reactor accident or any problem

involving a reactor which has resulted in the release of radioactivity. Since World War II the US Navy has only lost two submarines: one struck an underwater mountain, while a mechanical malfunction caused the second submarine to plunge into the ocean depths where the enormous pressure crushed its hull. The Russian Navy has lost 12 submarines due to problems with the reactors, including outright failure. It is careless about the environmental aspects of its nuclear programme and, according to its experts, it faces enormous costs to restore the programme's health and safety margins.

Discretion - Silence

In order to perform any mission it is not enough to be discreet, i.e. remain silent to avoid trouble. It is also necessary to be able to detect any potential aggressor.

The only efficient means known today for discovering the position of a submarine navigating beneath the surface of the ocean is the acoustic method commonly known as sonar. The electronic ears of a sonar system analyse the frequencies of the sound waves transmitted through the water and identify their origin.

Once below the surface the crucial imperative for any submarine is to possess the acoustic advantage over its potential aggressor. Specifically this means having a quieter propulsion system than the enemy vessel so as to detect its position before it detects yours. There are three main causes for the noise produced by submarines: the turbulence of the water along the hull, the noise produced by the propulsion system and the noise produced by the operation of various types of equipment such as motors, pumps, fans, valves and so on. Submarines are equipped with a total of 75,000 parts connected by 300 km of cables and 50 km of pipes. Every piece of equipment has to be fully independent from the hull and installed on flexible mountings or cradles isolated from the hull.

As for the reactor (Fig. 3), it produces pressurised steam and the same type of reactor is used in all American and European submarines. These reactors are characterised by the position of the steam generation system which is located directly above the reactor vessel. Water in the primary circuit is driven by convection between the reactor vessel and the steam generator unit, requiring no pumps under a wide range of operating conditions. The advantage of this design is the low level of noise as compared to noise generated from pump driven systems (Fig. 4).

The steam turbines drive two alternators: 1) the propulsion alternator produces the necessary electricity for the main electric engine which drives the propeller directly without an intervening noisy reduction gearbox; 2) the power alternator provides the electricity necessary to the ship's services. Instead of propellers, large submarines are now using pump jets but details of the mechanisms are jealously guarded military secrets.

For a speed greater than 10 to 12 knots, noise from both nuclear and conventional submarines is mostly of hydrodynamic origin. For speeds less than 10 to 12 knots most noise comes from the reduction gear, the reactor primary cooling pump (unless a convection system is used) and the propeller. A conventional submarine is silent when patrolling at 3 knots unless the batteries are being re-charged by noisy diesel generators.

Nuclear propulsion offers such a range of operational possibilities that it is difficult to imagine how submarines of the future could be anything but nuclear, except for those operating in small seas such as the Baltic or those designed for coastal duties, in which other AIP systems could be considered, such as fuel cells, although they would then face the difficulties of oxygen storage on board.

The French Navy is developing a small 2 megawatt reactor which could be used as an AIP propulsion system for 3000 tonne submarines enabling them to cruise at 8 knots indefinitely.

Conventional diesel-electric submarines have become increasingly vulnerable to airborne and shipborne advanced radar capable of detecting, at very long range, the snorkel mast and periscope when they are raised above the surface, and the wake created by them. Detection by these methods may cause the submarine to be lost even before reaching its patrol area.

The submarine batteries supplying the propulsion motors have to be charged regularly. Modern conventional submarines will spend 20% of their time at a snort station for a speed of advance (SOA) of 10 knots, 15% for an SOA of 8 knots, and 7% for an SOA of 5 knots. In the case of an Australian submarine this indiscretion ratio is actually more constraining than may appear because long distances have to be cruised at 8 or 10 knots before reaching the assigned patrol area. The journey from Sydney to the Strait of Lombok, for instance, lasts 20 days, of which 3 to 5 days are spent snorting. Nuclear propulsion would permit the same trip to be made in 8 days, with no snorkel indiscretion at all, the submarine remaining permanently submerged.

A conventional submarine on patrol at 3 to 4 knots would be snorting 2 hours a day, 2 hours that may prove extremely hazardous when a hostile aircraft has been ordered to clear the area for the benefit of an incoming task force, 2 hours that would be better spent quietly submerged and undetectable, searching for targets.

Mobility - Speed

Mobility in terms of submarine warfare means that a pre-determined speed be sustained for hours or days. When *HMS Conqueror* was despatched by the British Navy to the Falklands, she sailed 8000 nautical miles at more than 20 knots, submerged all the way, and could thus lock the Argentinian fleet in its harbour before it could take any action.

A modern submarine is equipped with acoustic sensors that permit it to detect, classify and track targets up to 100 km away. But the torpedoes and other weapons carried by the submarine have a strike range of no more than 30-40 km, In many instances the vessel has to get even closer to identify a selected target. The submarine captain is for most of the time in the position of a hunter who has to manoeuvre quickly in order to get into a firing position on a fast moving target, whereas a vessel equipped with diesel-electric propulsion might not be able to catch up.

If engaged in modern warfare, a diesel-electric submarine would soon be forced to a standstill by the limited capacity of its batteries, rather than be able to act as an aggressive hunter. In this context, the greatest advantage of nuclear propulsion is clearly evident: a nuclear submarine could track a fast running target for hours and days at a time—whether the quarry be either surface combatant or submarine — retaining the capability of firing at selected times on selected ships. A conventional submarine will have the opportunity to act once, and once only. The limitation imposed by its battery capacity will prevent it from keeping up with surface warships or merchant vessels, and thus it cannot act as an escort. Furthermore its range is limited by its fuel capacity.

The comparison of nuclear and conventional propulsion in terms of mobility and speed, is definitely in favour of nuclear propulsion. The validity of this assertion can be put in a few words: the conventional submarine can travel at a maximum speed of 20 knots for one hour only, approximately the distance between Garden Island and Palm

Beach, followed by several hours snorting *versus* unlimited sustained speed in submerged conditions for the nuclear submarine. In other words, the greater the speed the higher the chances for survival.

During World War II acoustic sensors and radar capable of detecting submarines at very long range were far from being as efficient as they are today and satellites did not exist. Nevertheless, 781 out of 842 or 93% of diesel-electric U-boats that saw action at the time were lost. Of the 38,000 German submariners 28,000 died and 5,000 were taken prisoners, i.e. there were 85% casualties. Towards the end of the war only two out of every ten U-boats that set out could expect to return. Would any come back today?

	Conventional	**Nuclear**
Tonnage, Submerged	3000 tonnes	3000 tonnes
Maximum Speed	22 knots (one hour only)	> 25 knots (unlimited time)
Construction Cost	1	1.3
Annual Maintenance	1	1.35

Patrol 3600 mile from Base:

Transit Speed	10 knots	18 knots
Indiscretion Ratio	22% (snorting)	0%
Transit Time	15 days x 2	8.5 days x 2
Patrolling Time	40 days	53 days
Patrolling Speed	3.5 knots	10 knots
Indiscretion Ratio	5% (snorting)	0%

To permanently maintain 2 submarines over the patrolling area, including maintenance and transit time:

Required Number of Submarines	8	5
Purchase Price	8	6.5
Maintenance cost per annum	8	6.75

Advantage is in favour of nuclear propulsion. The price difference will more than cover the cost of the infrastructure required for supporting the nuclear fleet, which is estimated at approximately 75% of the total price of one unit.

Table 1

COMPARING COSTS OF NUCLEAR AND CONVENTIONAL SUBMARINES

Comparison is valid if both submarines are of similar capacity, with similar weapon systems and the same number of torpedoes and missiles.

In this situation the price of *one* nuclear propelled submarine is 30% higher than for a conventional submarine, and its maintenance costs 35% more, but the vessel is capable of far superior performance, so much so that the price comparison should not be restricted to the number of units per fleet.

As an example, in order to permanently maintain two submarines patrolling over a distant area, the respective requirements are set out in Table 2:

whereas nuclear submarines are fast vehicles of manoeuvre.

All advantages are on the side of nuclear propulsion. The significantly lower operating costs of nuclear submarines, as stated in the table, will more than cover the cost of the infrastructure required for supporting the nuclear fleet, which is estimated at approximately 75% of the total price of one unit. It is also relevant that while a 3000 tonne conventional submarine will require 25,000 tonnes of fuel during its operational life, not forgetting handling problems, only one tonne of nuclear fuel would be used over the same period.

8 Conventional submarines costing	8 x 1	=	8
	or		
5 Nuclear submarines costing	5 x 1.3	=	6.5.

Table 2

These figures apply to 2 equivalent 3000 tonne dived submarines with the following salient features.

A nuclear submarine has a much higher transit speed, not having to charge batteries for 20% of the time at sea with noisy diesel-generators broadcasting its position. Furthermore, it will cruise at 10 to15 knots over the patrolling area instead of only 3 to 4 knots for the diesel electric unit.

The area covered by the nuclear vessel is 3 to 4 times greater for the same number of days at sea, with zero indiscretion ratio (Fig. 7). Thanks to its faster transit speed a nuclear submarine will spend 53 days permanently submerged over the area concerned, whereas a conventional vessel can only remain 40 days, occasionally snorting. Diesel submarines are warships of position,

In a nation where 96% of our imports and exports depend on ships, conventional submarines could not escort and protect any of them. The use of conventional technology would condemn our young sailors to overwhelming inferiority should an emergency occur. Would anyone like to be a sailor on board what the German U-boat Commander Herbert Werner called 'iron coffins', in the event of a conflict in the Indian Ocean?

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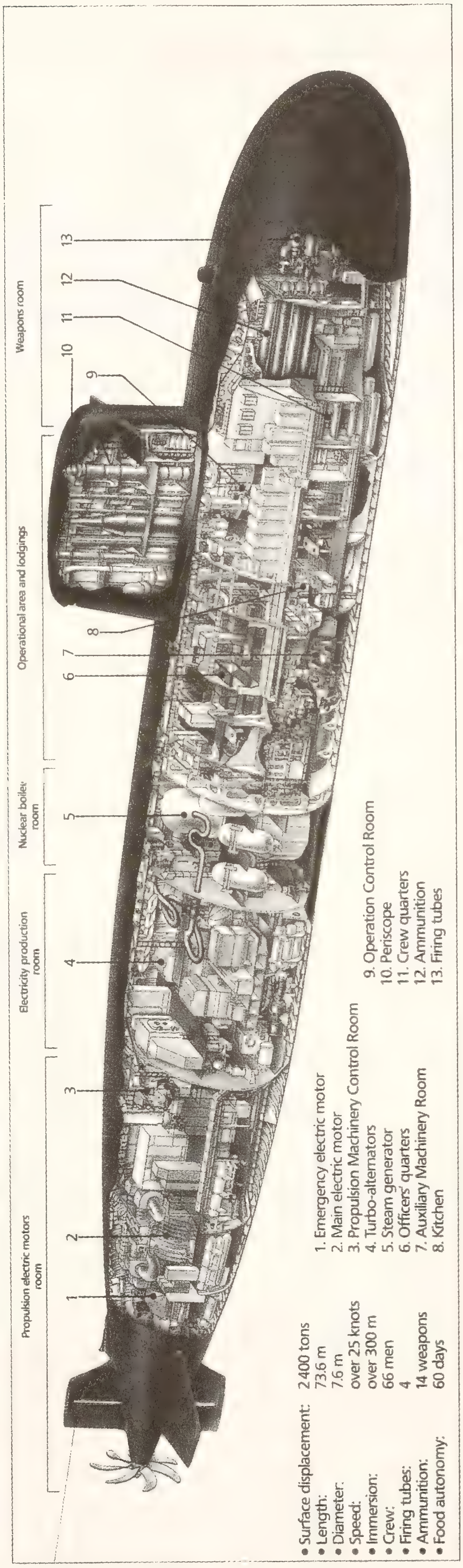
SSN, "RUBIS" CLASS, "AMETHYSTE" BATCH



The SSBN

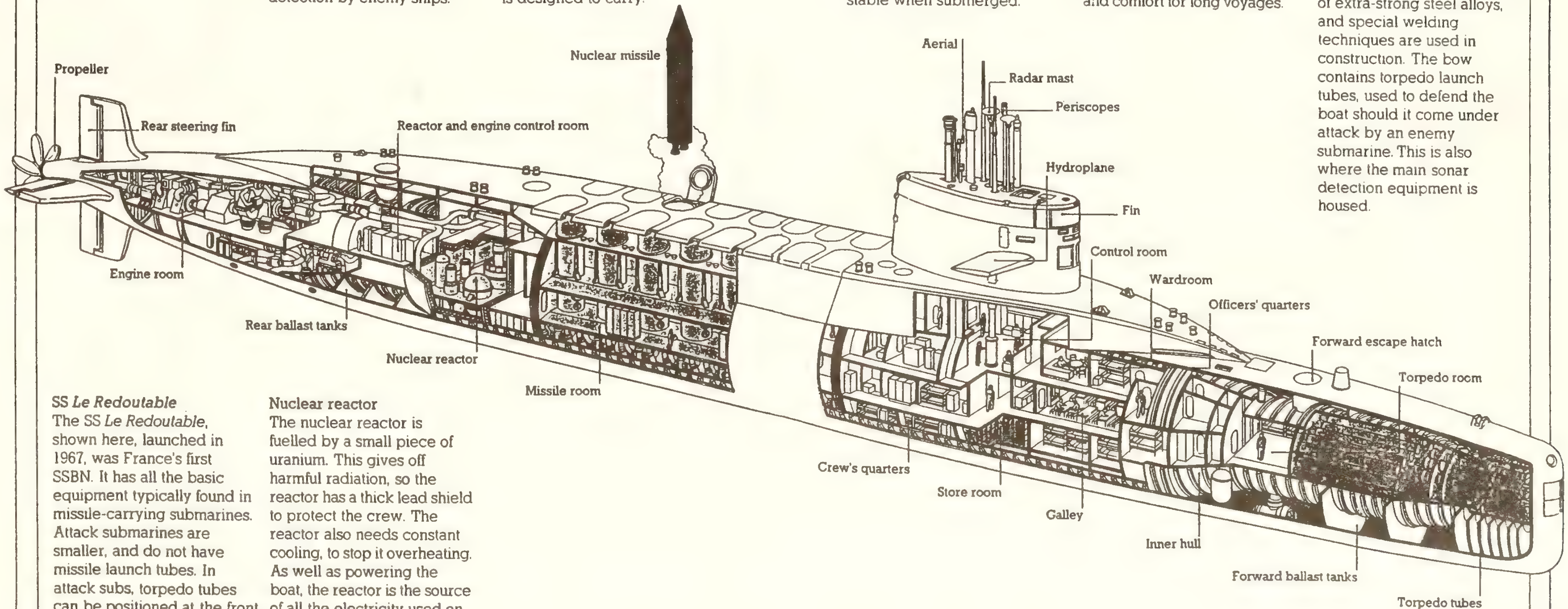
The powertrain
The energy generated in the reactor creates steam which turns a series of turbines. These are connected to the propeller by a drive shaft and gears. Great effort is spent to make the submarine run as quietly as possible to avoid detection by enemy ships.

Missiles
At the centre of the submarine, to the rear of the fin, is a raised section of the hull that holds two lines of vertically-mounted missile launch tubes. The size of an SSBN is dictated by the size and number of the missiles it is designed to carry.

The Fin or Sail
The fin or sail acts as a bridge when the sub has surfaced and contains the submarine's aerials, snorkels, periscopes and other equipment. Hydroplanes attached to the side help keep the sub stable when submerged.

Living Quarters
Beneath the fin are the crew's quarters, officers' wardrooms, storerooms, galleys and the operations and communications centre of the sub. With crews of up to 140 men, great care is taken to provide recreation and comfort for long voyages.

Hull and bows
A submarine has an inner and outer hull. Between the two are ballast tanks which are flooded with water when the submarine dives. In order to withstand high water pressures when submerged, the hull is made of extra-strong steel alloys, and special welding techniques are used in construction. The bow contains torpedo launch tubes, used to defend the boat should it come under attack by an enemy submarine. This is also where the main sonar detection equipment is housed.



SS *Le Redoutable*
The SS *Le Redoutable*, shown here, launched in 1967, was France's first SSBN. It has all the basic equipment typically found in missile-carrying submarines. Attack submarines are smaller, and do not have missile launch tubes. In attack subs, torpedo tubes can be positioned at the front, rear and middle of the hull.

Nuclear reactor
The nuclear reactor is fuelled by a small piece of uranium. This gives off harmful radiation, so the reactor has a thick lead shield to protect the crew. The reactor also needs constant cooling, to stop it overheating. As well as powering the boat, the reactor is the source of all the electricity used on board the sub.

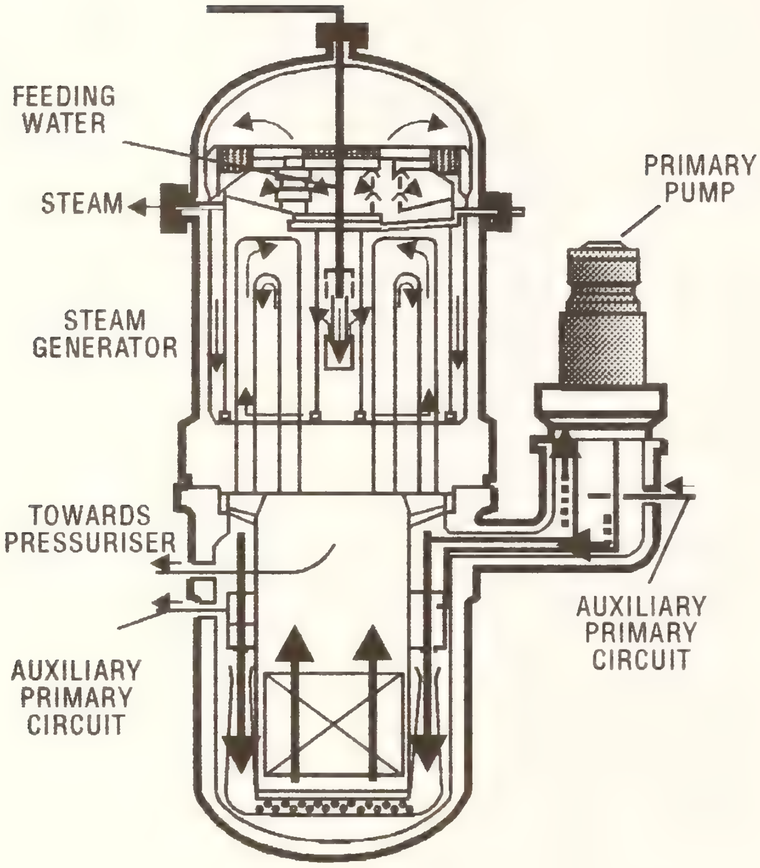
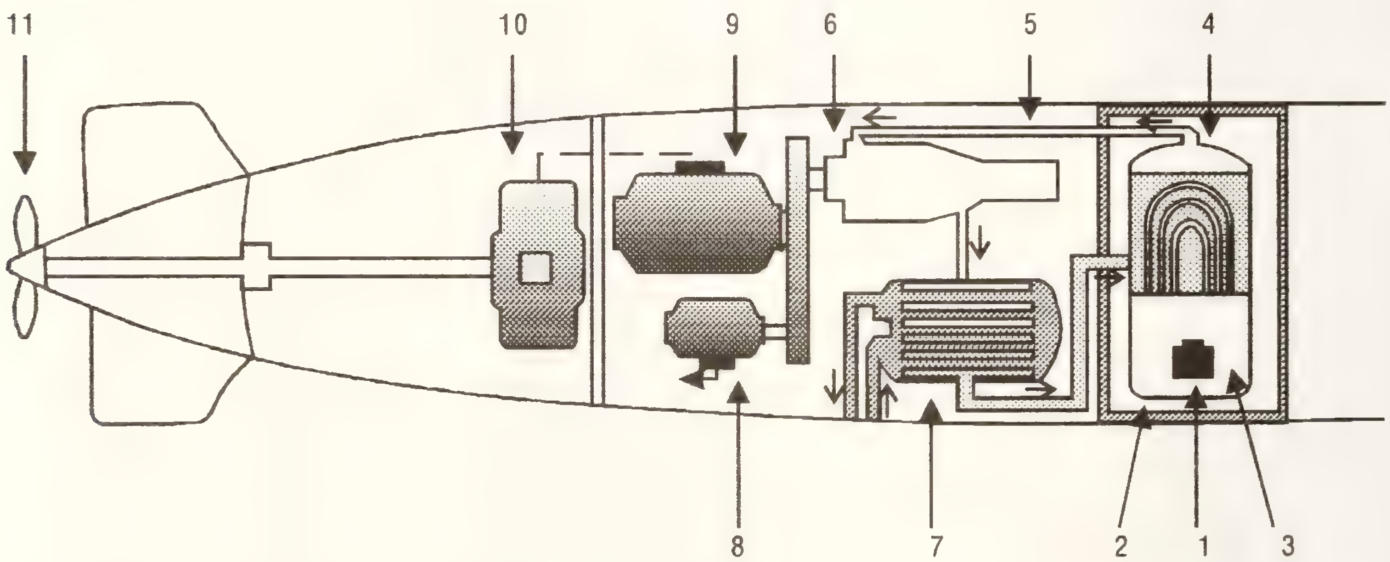


Fig. 3 (*left*). Nuclear boiler.

Fig. 4 (*below*). Propulsion: nuclear fuels **1** contained in reactor vessel **2** boils the primary water **3**. This water circulates by natural convection into steam generator **4** and causes the evaporation of the secondary water **5** to feed the turbines **6**. The secondary water is cooled in the condenser **7** before being returned to the steam generator. Each turbine drives two alternators **8** and **9.** The propulsion alternator **9** produces the necessary electricity for the main electric motor **10** that drives the propeller **11**. Power alternator **8** provides the necessary electricity for the ship's services.



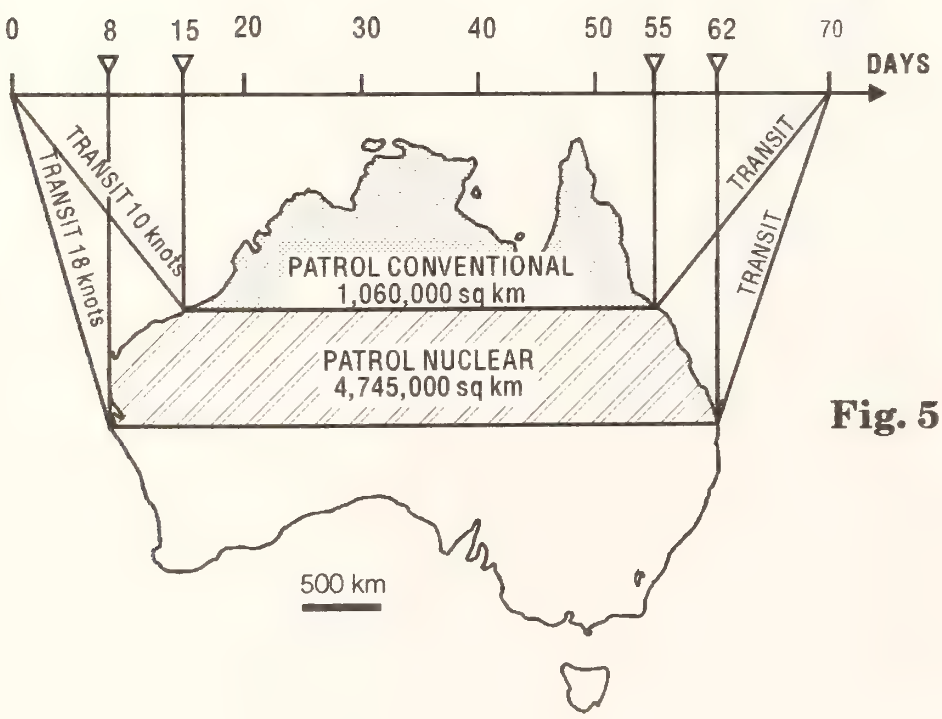


Fig. 5. Area covered during patrol.

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Theses Abstracts

THE EFFECT OF TENURE ON RANGE MANAGEMENT

A comparison of perpetual and pastoral leases in north-east South Australia

MICHAEL BRETT

Abstract of a Thesis Submitted for the Degree of Master of Science
at The University of Adelaide

South Australia has long had perpetual and pastoral leases, used for grazing sheep on arid native pastures, lying side by side. This works undertakes a thoroughly structured data collection and analysis to determine to what degree the nature of each leasing system has influenced vegetation resources in the Lower North East

An initial study investigated the nature of grazing effects on vegetation patterns in three locations widely separated along the tenure division. Influence analysis showed that the small-scale variation of the vegetation was appreciable, an observation which enabled the design of a regional study.

The broad-scale investigation formed the greater part of this work. It detailed the leasing histories of six pastoral and six perpetual lease runs, and explored the degree to which cross-tenure vegetation differences were dependent on them. A multiple regression technique was used so that the influence of many environmental and managerial factors could be taken into account

This research found that the perpetual leases were more degraded than the pastoral. Although the difference in range condition was small, it was significant and involved the most dominant perennial species (such as *Maireana edifolia* and *Atriplex vesicaria*) as well as important features such as the cover of scald and total bush.

The cross-tenure vegetation differences were most strongly and most often correlated with the discontinuity of lease ownership. The lighly significant differences in ownership discontinuity between tenure types was concluded to result from differential management attitudes engendered by each type. It was argued that such attitudes stemmed from the disparity between tenures in controls on the intensity of resource use. The difference between perpetual and pastoral terms was seen to have little effect on management.

On the basis of these results, the recent changes to the pastoral tenure system and the Soil Conservation Act must be seen to be encouraging, if properly implemented. However, the inequities which remain between the tenure systems are predicted to continue to cause the rate of degradation on perpetual leases to be greater than that on pastogal.

[Note that legislative changes since 1991 are outside the scope of this thesis].

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Theses Abstracts

THE ECOLOGY OF CEREAL RUST MITE *ABACARUS HYSTRIX* (NALEPA) IN IRRIGATED PERENNIAL DAIRY PASTURES IN SOUTH AUSTRALIA

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Abstract of a Thesis Submitted for the Degree of Doctor of Philosophy at The University of Adelaide

The cereal rust mite *Abacarus hystrix* (Acari: Eriophyidae), vector of ryegrass mosaic virus in temperate perennial pastures, was initially recorded in Australia in 1989. In South Australia, the mites were found to be common in irrigated perennial pastures in the South Mt Lofty Ranges and Lower Murray Valley, and in dry land pastures of the Fleurieu Peninsula. *A. hystrix* was numerically dominant in mixed populations with mites of the genera Aculodes and *Aceria*.

Examination of herbaria specimens of *Lolium* spp. indicated that *A. hystrix* was present in the South Mt Lofty Ranges in 1972, and in Victoria in 1982. The mites may have been introduced into Australia in the late 1960's.

Study of the seasonal dynamics of *A. hystrix* populations in South Australian irrigated perennial dairy pastures indicated that numbers were highest in summer and early autumn. The intensity and frequency of grazing had strong influence on the regulation of eriophyid populations. Hard strip grazing of pastures at infrequent intervals retarded the recovery of mite populations more than frequent, lax grazing rotations. The rate of recovery of mite populations following grazing was determined by the size of the residual population, and shifts in leaf age-structure and quality induced by defoliation.

In a glasshouse pot trial, infection of perennial ryegrass by the endophyte *Acremonium lolii* did not affect the rate of *A. hystrix* population development orthe rate of movement of mites between plants, although the expression of RMV leaf symptoms was reduced.

There was a degree of population stratification vertically through pastures, with a greater proportion of pre-reproductive adults and deutonymphs occurring closest to the base of the sward. High summer temperatures may decrease mite numbers in heavily grazed swards. In a field experiment, the rate of mite population development was correlated with the recovery of perennial ryegrass following defoliation. Population development was significantly reduced after exposure to temperatures >39°C and >44°C in plots mown to 5 and 10 cm stubble height, respectively.

Temperatures of 29°C, but not changes in photoperiod, were found to accelerate the rate of wax production in *A. hystrix*. Possible functions of wax filaments in drag maximisation and water conservation were investigated. 'Waxy' mites were found to have lower rates of desiccation-induced mortality, and increased total drag relative to cuticular surface area. The increased non-cuticular surface area associated with the

development of wax filaments may increase wind shear stress on mites within the wind velocity gradient at the leaf margin, enhance air-borne buoyancy and prolong the duration of air-borne survival during migration. Polyphenically-derived wax production in *A. hystrix* should, consequently, enhance the fitness of 'waxy' individuals migrating under summer conditions.

Large populations of *Aceria* were recorded in Australian wheat crops in 1993. There is evidence that two forms of Aceria may commonly occur on wheat in Australia. Perennial pastures and volunteer grasses may act as important over-summer refuge areas for the mites.

Higher numbers of mites did not result in a greater incidence of infection by RMV in study pastures. Control of mite populations in established pastures, in particular, is unlikely to decrease production losses due to RMV infection.

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Theses Abstracts

NEGOTIATING DIETARY KNOWLEDGE INSIDE AND OUTSIDE LABORATORIES: THE CHOLESTEROL CONTROVERSY

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Abstract of a Thesis submitted for the Degree of Doctor of Philosophy
at the University of New South Wales, Sydney

For more than forty years, doctors and scientists have disagreed about the extent to which dietary saturated fat and high serum cholesterol levels contribute to the development of coronary heart disease (CHD), and whether or not the disease can be prevented by dietary change. Although large amounts of time, effort and money have been devoted to research, experiments have often yielded inconclusive and contradictory results.

This thesis analyses the development of knowledge and policies relating to dietary fat, cholesterol and CHD. It takes a symmetrical stance towards the knowledge claims under investigation. That is, it does not try to ascertain which particular version of the 'facts is true, or to argue for or against the efficacy of dietary change. Instead it seeks to explicate the social context in which medical science and dietary policies developed. The central problem addressed by the study may be summed up as follows: How and why, in the midst of so much scientific uncertainty, did so many people come to believe that dietary change could prevent heart disease?

The study takes a historical perspective. It draws upon archival material from a variety of sources, including scientific articles, food advertisements, business journals, policy documents, newspapers, popular magazines and the internee These sources indicate that the development of knowledge and policy relating to diet and CHD was a complex interactive process which cannot be divorced from the cultural, political and commercial contexts in which it occurred.

The putative links between diet and CHD were first popularised by entrepreneurial scientists in the affluent society of 1950s America, at a time when the 'facts' were meagre and tentative. These scientists were motivated by therapeutic activism, a drive to 'do something' despite incomplete knowledge. Advice to lower fat consumption struck a receptive chord among sectors of the lay public. Their interest in polyunsaturated fat and cholesterol was further stimulated by commercial interests, which used the new claims to sell products. Cholesterol-lowering diets soon became popular.

The first cautious endorsement of dietary change by an official medical organisation (the American Heart Association) appeared in 1960. It was provisional, subject to the attainment of the definitive proof. However, the changing social circumstances of the United States during subsequent decades favoured the retention and enhancement of policies advocating reductions in fat and cholesterol intakes. As scientists strove to provide Ode proof, food activists, health policy-makers and advocates of 'healthy lifestyles' adopted and

promoted dietary change as a progressive cause. It provided a means of resisting the undesirable side-effects of affluence. Dietary self-denial and exercise, as preached by Nathan Pritikin and others, promised physical and almost spiritual renewal and salvation.

There were only two groups of people who questioned the wisdom of the dietary recommendations - scientists who insisted that policies be based on unequivocal evidence of efficacy, and those sectors of the food industry whose profits depended on the sale of products containing saturated fats and cholesterol. During the 1970s, these industries mounted a number of campaigns which highlighted the unstable and uncertain aspects of the scientific knowledge linking their products to disease.

Although they were able to recruit sceptical scientists as allies, their challenges were unsuccessful. They could not muster sufficient authority to overturn the claims of the many prestigious medical organisations which supported dietary change. Indeed, the sceptical scientists lost legitimacy because of their alliances with industry. Although the definitive proof remained elusive, policy statements in favour of dietary change accumulated. The scientific, government and medical organisations that issued these statements found it difficult to turn back. In the early 1980s, several large, expensive trials designed to test the effects of cholesterol-lowering regimes produced equivocal results. Scientists shaped these results into endorsements for dietary change and intensified their policies. A diverse range of people had already decided that dietary change was desirable and the scientific results were shaped to reinforce the policies which preceded them.

The study draws on a range of theoretical perspectives within the sociologies of science and medicine. The overall approach is constructivist in nature and makes use of actor-network theory, symbolic interactionism, the ideas of Michel Foucault, and recent work on lay understanding of scientific knowledge.

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Theses Abstracts

EXPRESSIONS OF INNER FREEDOM

An Experimental Study of the Scattering and Fusion of Nuclei at Energies Spanning the Coulomb Barrier

H. TIMMERS

Abstract of a Thesis Submitted for the Degree of Doctor of Philosophy at The Australian National University, Canberra, June 1996

This study investigates the fusion and scattering of nuclei at energies spanning the Coulomb barrier. The coupling of the relative motion of the nuclei to internal degrees of freedom can be thought to give rise to a distribution of potential barriers.

Two new methods to extract representations of these potential barrier distributions are suggested using the eigen-channel model. The new techniques are based on measurements of quasi-elastic and elastic backscattering excitation functions, from which the representations are extracted by differentiation. A third method utilizing transfer excitation functions is introduced using qualitative arguments. The techniques are investigated experimentally for the reactions $^{16}O + ^{92}Zr$, $^{144,154}Sm$, ^{186}W and ^{208}Pb. The results are compared with barrier distribution representations obtained from fusion data. The methods are further explored using the systems $^{40}Ca + ^{90,96}Zr$ and $^{32}S + ^{208}Pb$, for which scattering and fusion excitation functions have been measured. The new barrier distribution representations are consistent with the one from fusion. They are direct evidence of the effects of the internal degrees of freedom on channels other than the fusion channel.

The new representations are, however, less sensitive to the barrier distribution compared to their fusion counterpart. This observation is investigated using coupled-channels calculations. They suggest that residual weak reaction channels, which are not included in the coupling matrix, are responsible for the reduction in sensitivity. In the case of quasi-elastic scattering a distortion of the barrier structure above the average barrier is observed. This effect appears to be due to the de-phasing of the scattering amplitudes contributing to each eigen-channel. Using the heaviest system, $^{32}S + ^{208}Pb$, it is demonstrated that there is no improvement in sensitivity to the barrier distribution for systems with large Sommerfeld parameters. This suggests that diffraction effects are not likely to be the cause of the sensitivity reduction.

The new techniques may be employed successfully in systems with pronounced barrier structure below the average barrier. This is the case for the reactions $^{40}Ca + ^{90,96}Zr$. It is shown that for these systems the quasi-elastic scattering and the fusion representations of the barrier distribution contain the same information. The extracted barrier distributions for the two reactions are distinctively different. They are compared to assess the relative importance of collective excitations and neutron transfer in fusion. Exact coupled-channels calculations show that the distribution for $^{40}Ca + ^{90}Zr$ arises from coupling of the relative

motion to double phonon excitations of ^{90}Zr. Further calculations suggest that the reaction ^{40}Ca + ^{96}Zr involves additional coupling to sequential neutrontransfer, which is proposed to be a precursor of neutron-neck formation.

Double phonon excitations are also seen to be important in the system ^{32}S + ^{208}Pb, for which the barrier distribution representations show in addition signatures of one and two neutron transfer.

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(Manuscript received 1.5.97)

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Annual Report of Council

for the year ended 31st March 1997

PATRONS

The Council wishes to express its gratitude to His Excellency the Honourable Sir William Deane, AC, KBE, Governor General of the Commonwealth of Australia, and His Excellency the Honourable Gordon Samuels AC, Governor of New South Wales for their continuing support as Patrons of the Society.

MEETINGS

Seven Ordinary Monthly Meetings and the 129th Annual General Meeting were held during the year. The Annual General Meeting and five of the Ordinary Monthly Meetings were held at the Australian Museum. One Ordinary Monthly Meeting was held at the Bankstown Campus of the University of Western Sydney.

Special Meeting and Events

June 12th 1996: The 30th Liversidge Research Lecture in Chemistry (1996) was delivered by Professor D.J. Swaine. His talk was entitled, "Trace Elements in Coal Science" (see *Journal & Proceedings* vol. 129, pp. 139-148). The lecture was delivered as a joint meeting with the Sydney University Chemical Society at the University of Sydney.

July 6th 1996: The regular July General Monthly Meeting was substituted by a Field Trip to Kurnell, celebrating the 175th Anniversary of the formation of The Philosophical Society of Australasia (founded July 4th 1821), led by Dr. D. Branagan.

February 11th 1997: The Society was co-sponsor with the Australian Institute of Energy and the Australian Nuclear Association of a meeting held at The Institute of Engineers, Milson's Point. Topic: "The Review of the National Greenshouse Response Strategy and the Commonwealth Greenhouse Challenge".

March 26th 1997: A very succesful Annual Dinner was held at the University and Schools Club. His Excellency The Honourable Gordon Samuels AC, Governor of New South Wales and joint Patron of the Society, Mrs Samuels and 48 Members and guests were present. His Excellency gave an Occasional Address (see p. 65) and presented the Society's Awards for 1996 to: Miss P.M. Callaghan (Royal Society of New South Wales Medal), Profesor K. Rohde (Clarke Medal - Zoology), and Dr P. Robinson (Edeworth David Medal).

Meetings of Council

Eleven meetings of Council were held at the Society's Offices at North Ryde. Attendances were as follows: Dr R.S. Bhathal (0), Dr D.F. Branagan (6), Miss P.M. Callaghan (7), Dr R.R. Coenraads (2), Mr G.W.K. Ford (3) [subst Dr P.R. Evans (2)], Mr J.R. Hardie (7), Mrs Krysko v. Tryst (9), Dr M. Lake (8), Dr G.C. Lowenthal (7), Dr D.J. O'Connor (7), Dr E.W.C. Potter (6), Dr K.A. Rickard (4), Prof. D.J. Swaine (8), Prof. W.E. Smith (8), Dr F.L. Sutherland (6), Dr K.L. Grose (10), Mr H.R. Perry (7). Dr N.V.P. Kelvin (coopted - 2).

PUBLICATIONS

Volume 129, Parts 1,2,3, and 4 of the *Journal and Proceedings of the Royal Society* were published during the year. The volume incorporated the Presidential Address for 1996, the *48th Clarke Memorial Lecture* (1995), the *Pollock Memorial Lecture* (1996), the *30th Liversidge Research Lecture* (1996), three research papers, including a Biographical Register of Earlier Members (1850 to 1866), and the Annual Report of Council for 1995-

96. Furthermore, nine Abstracts of higher degree theses were published covering a wide range of disciplines that included: geology, medicine, Australian aboriginal ethnoarchaeologic studies, music, agriculture, botany and linguistics.

Council wishes to thank all the voluntary referees who assessed the papers offered for publication.

Seven issues of the *Bulletin* were published during the year. Council's thanks are extended to the various authors of short articles for their contributions. Very sincere thanks are expressed to Mr Ted O'Keeffe for all his efforts in the preparation of the *Bulletin* throughout the year.

Council received several applications from Australian as well as overseas authors to reproduce material from the *Journal and Proceedings.*

AWARDS

The following awards were made for 1996:-

Royal Society of New South Wales Medal (For achievements in science and service to the Society) - Miss P.M. Callaghan.

Clarke Medal (in Zoology) - Professor Klaus Rohde, Department of Zoology, The University of New England.

Edgworth David Medal (For distinguished contributions to Australian science by a young scientist under 35 years of age) - Dr Peter Alexander Robinson of the School of Physics, The University of Sydney.

The James Cook Medal, the Walter Burfitt Prize and the Archibald Olle Prize were not awarded in 1996.

MEMBERSHIP

At 31sth March 1997 membership of the Society was: Patrons 2: Honorary Members 16: Members and Life Members 280: Associates and Spouse Members 23: Total 321.

Two new Honorary Members were elected: Emeritus Professor Di. Yerbury and Dr K.G. McCracken, AO.

The deaths of the following Members were announced with regret: H.O. Fletcher and N.Gray.

OFFICE

The Society continued during the year to lease for its office and library a half-share of Convocation House, 134 Herring Road, North Ryde, on the southeastern edge of the Macquarie University Campus. The Council is grateful to the University for continuing the lease. Council greatly appreciates the secretarial assistance rendered by Mrs V. Chandler during the past year.

LIBRARY REPORT

Acquisition of literature by gift and exchange has been continued at North Ryde. Material from overseas and some Australian literature are sent to the Dixson Library at the University of New England. The remaining Australian material is retained in Sydney. A list of the latter is compiled biannually and incorporated in Council Minutes. It also appears in abbreviated form in the *Bulletin.* Members are encouraged to consult these acquisitions at Head Office. At the suggestion of Prof. Loxton, Deputy Vice Chancellor (Academic), Macquarie University, Council is exploring the possibility of a display of our literature in Macquarie University Library in 1998.

Council thanks Mr Karl Schmude and his staff, particularly Mrs Helen Stokes for their continuing efficient maintainance of the processing and availability of the Society's collection in the Dixson Library. This collection is now listed in the National Union Catalogue of Serials with the rest of the Dixson Library's holdings and is thus

available for inter-library loans (more exactly, for photocopying of articles). [Material in the Head Office library is not listed in the Union catalogue].

Loan of Paintings

The Society agreed to lend free of charge two paintings owned by the Society to the National Gallery, Canberra, to be part of the exhibition, "A Clever Country" (Scientists in Australia) held in Canberra 21 June-3 November 1996:

1. Professor Sir T.W. Edgeworth David (1858-1934);
2. Reverend W.B. Clarke FRS (1798-1878). [Council gave the Mitchell Library, permission to release the painting for the duration of the exhibition].

A total of 22 or one third of the 71 portraits exhibited were of Members of the Society.

Honorary Members

Sir Philip Baxter
Prof. Arthur Birch
Sir Macfarlane Burnett
Sir John Eccles
Lord Florey
Prof. Dorothy Hill
Baron Ferdinand von Muelller (1875)
Sir Gustav Nossel
Sir Mark Oliphant
Sir Baldwin Spenser (1894)
Dr J.P. Wild
Prof. J.T. Wilson (1922)
Sir Thomas Brisbane (Founder Member)

Members

Lawrence Hargrave
Rev. W.B. Clarke
Sir T.W. Edgeworth David
Prof. J.C. Jaeger
Prof. Abercrombie Lawson (1913)
Sir Douglas Mawson
John Tebbutt
Alexander McLeay
Sir George A. Julius (1911)

SOUTHERN HIGHLANDS BRANCH REPORT

The Branch held eight well-attended meetings, details of which are given in ABSTRACT OF PROCEEDINGS, below.

NEW ENGLAND BRANCH REPORT

The New England Branch, based in Armidale NE, held two meetings during 1996, details of which are given in ABSTRACT OF PROCEEDINGS, below.

ABSTRACTS OF PROCEEDINGS

April 3rd 1996

The 129th Annual General Meeting and 1056th General Monthly Meeting was held at the Australian Museum, Sydney. The President, Dr D.F. Branagan was in the Chair and 30 members and visitors were present. The Annual Report of Council and the Financial Report for 1995-96 were adopted. Messrs Wyllie and Puttock were elected auditors for 1996-97.

The following Awards for 1995 were announced and presented by the President:

The Royal Society of New South Wales Medal
Dr G.C. Lowenthal

Clarke Medal (Geology)
Professor C. McA. Powell

Edgeworth David Medal
Dr. A.B.Murphy

Walter Burfitt Prize
Dr R.M. Manchester

The James Cook Medal and the Archibald Olle Prize were not awarded in 1995.

The following Office-bearers and Council Members were elected for 1996/97:

President	Dr K.L. Grose
Vice Presidents	Dr D.F. Branagan
	Mr J.R. Hardie
	Prof. J.H. Loxton
	Dr E.C. Potter

	Prof. W.E. Smith
	Prof. D.J. Swaine
Hon. Secretaries	
General	Mr G.W.K. Ford
Editorial	Mrs M. Krysko v. Tryst
Hon. Treasurer	Dr D.J. O'Connor
Hon. Librarian	Miss P.M. Callaghan
Members of Council	
	Dr R.S. Bhathal
	Dr R.R. Coenraads
	Dr M. Lake
	Dr G.C. Lowethal
	Mr K.A. Rickard
	Dr F.L. Sutherland
New England Representative	
	Prof. S.C. Haydon
Southern Highland Representative	
	Mr H.R. Perry

At this point, the retiring President, Dr. D.F. Branagan yielded the Chair to the incoming President, Dr K.L. Grose. Dr Branagan then presented his Presidential Address, "Bricks, Brawn, and Brains - Two Centuries of Geology and Engineering in the Sydney Region". A vote of thanks was proposed by Professor D.J. Swaine.

May 1st 1996
The 1057th General Monthly Meeting was held at the Australian Museum. Mr A. McQueen presented a talk, "Ensign Barrallier - square peg in a foreign land".

August 7th 1996
The 1059th General Monthly Meeting was held at the Australian Museum. The President, Dr R.L. Grose was in the Chair and 15 members and visitors were present. Professor M. Wilson presented a talk, "New Applications of solid state nuclear magnetic resonance".

September 4th 1996
The 1060th General Monthly Meeting was held at The Australian Museum. The President, Dr R.L. Grose was in the Chair and 10 members and visitors were present. Mr T.C.T. Hubble presented his talk, "River Bank Erosion Project, Nepean River, NSW, evaluating the relative contributions of long-term geomorphic change and recent human influence". A vote of thanks was moved by Mr J. Grover.

October 2nd 1996
The 1061st General Monthly Meeting was held at The Bankstown Campus, University of Western Sydney. Professor H.W. Marsh gave his talk, "A multidimensional, hierarchical, self-concept: theory, measurement, research".

November 6th 1996
The 1062nd General Monthly Meeting was held at The Australian Museum. Dr G. Holland delivered a talk entitled, "Something attempted, something done: the useful author of "Potter on Pigs"".

New England Branch

Thursday, 12th of September 1996:
Two organizations, the Royal Society of New South Wales, New England Branch, and the Australian Federation of University Women (Armidale Branch) held a combined meeting at the Somerville Lecture Theatre of the University of New England. Professor S.C. Hayden chaired the meeting, which was attended by 63 members and friends.

Dr. Briggs, Senior Assistant Director (Scientific) at the Royal Botanic Gardens in Sydney, Corresponding Member of the Botanical Society of America, and Clarke Medallist of the Royal Society of New South Wales, addressed the meeting on the recently discovered and now widely-publicised Wollemi Pine. The title of her talk was:

"Research on the Wollemi Pine - studying a living fossil". Dr. Briggs supplied the following notes:

Wollomia nobilis, the Wollemi Pine, is a most handsome species, a tall tree, with very few living individuals, not scientifically described or named until 1996 and a survivor of an evolutionary lineage that extends back in the fossil record more than 100 million years. It has captured world attention, rivalling the Chinese "Dawn Redwood". There has been some excess of media enthusiasm in describing it as the "Dinosaur Pine" and "the botanical find of the century". Studies on the Wollemi Pine contribute to our understanding of the plant family to which it belongs, the history of Southern Hemisphere floras, and to the interpretation of fossils from a range of south-eastern Australian localities. Dr Briggs will speak of the remarkable opportunity it has presented to combine a range of scientific approaches and to investigate the genetics and survival of an extremely rare species.

The meeting was preceded by a dinner at the University Staff Club. Dr Briggs attended the dinner as a guest of the two Societies.

Thursday, 24th of October, 1996

The meeting was held at the Somerville Lecture Theatre of the University of New England. Professor John Milburn chaired the meeting, which was attended by 42 members and friends. Professor D.A. Baker of Wye College of the University of London addressed the audience on "2020 Vision - The Impact of Plant Molecular Genetics on Crop Production". The speaker supplied the following notes:

As the carrying capacity of our planet is predicted to be exceeded in the next thirty years, what technologies: can be implemented to avert malnutrition and famine of a global scale? Only increased crop production can provide the additional food and many production systems have reached their maximum achievable levels using current technologies. The introduction of genetic engineering allows for a possible expansion of crop production in both quantitative and qualitative terms. The possible economic benefits and environmental hazards of applying this technology will be presented.

Southern Branch

Thursday 7th March 1996

Following the Branch's Annual General Meeting, Dr Jennifer Nicholls of the Centre for Theoretical Astrophysics at the University of Sydney spoke to 30 members and visitors on "The Riddle in the Middle of the Galactic Centre". Vote of thanks: Commander David Robertson.

Thursday 2nd May 1996

Dr Garth Hogg, of ANSTO, Lucas Heights, addressed members on "Nuclear Science and Technology in Australia".

Thursday 13th June 1996

Professor John Mulveney, of the Australian Academy of the Humanities spoke to 36 members and visitors on "Macassan Indonesians and the history of Arnhem Land across 300 years". Vote of thanks: Commander David Robertson.

Thursday 8th August 1996

Dr John Harris, of the Environmental Division of ANSTO spoke on "The disposal of low level nuclear waste in Australia" and "Acid mine drainage". Vote of thanks: Dr Garth Hogg. The lecture was attended by 30 members and visitors.

Thursday 5th September 1996

Dr Robert Coenraads, School of Earth Sciences, Macquarie University, spoke to 30 members and visitors on "Diamonds and bacterial gold in Venezuela", and told of the

new insights gained when materials brought back to Australia were examined in scanning electron microphotographs. Vote of thanks: Dr Kenneth McCracken.

Thursday 12th October 1996
Dr David Tranter spoke to 33 members and visitors on, and gave homely demonstrations of, "The Simple side of complexity: El Niño and other strange phenomena". Vote of thanks: Mr Roy Perry.

Thursday 7th November 1996
Following presentation by Dr Kenneth McCracken of the Branch's Science Awards* to Year 11 science students Johanna Rheinberger of Frensham School, and Patrick Campbell of Chevalier College, Dr Rhagbir Bhatal, a former President of the Royal Society of NSW, addressed 37 members and guests on the subject of "The search for extra-terrestrial life forms". Vote of thanks: Mr Roy Perry.

Wednesday 22nd January 1997
Professor L.W. Davies, before 30 members and visitors, traced the development of wireless communications and electronics in Australia from the formation of the Australian company AWA Ltd in 1913 to that of OTC (Australia) in 1946. Vote of thanks: Dr Kenneth McCracken AO.

Thursday 6th March 1997
At the Branch's Annual General Meeting the following were elected to the Branch's committee for 1997/98.

Chairman	Dr K.G. McCracken AO
Vice Chairmen	Mr R.H. Perry
	Ms C.M. Staubmer
	Mr C.F. Wilmot
Hon. Treasurer	Mr M. Lemann
Hon Secretary	Cmdr D. Robinson.

Dr Lin Sutherland spoke after the election on the subject, "Earthquakes and volcanoes in the southern Sydney region".

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* **The Southern Highlands Branch Science Award**, for the Most Outstanding Science Student in Year 11, attracted nominations from four of the six secondary schools in the district. The prize this year was increased to re-imburse the winners for the first year of costs not covered by the Commonwealth Higher Education Scheme (HECS), namely books, and compulsory University Union Fees, payable when the winner commences a science oriented course at a Tertiary education establishment in 1998.

FINANCIAL STATEMENTS FOR THE YEAR ENDED 31 DECEMBER 1996

AUDITORS REPORT TO THE MEMBERS

Scope
We have audited the financial report, being a special purpose financial report of The Royal Society of New South Wales for the year ended 31 December 1996 as set out on pages 2-11. The society's officers are responsible for the preparation and presentation of the financial statements and the information they contain. We have conducted an independent audit of these financial statements in order to express and opinion on them to the members of the society.

The financial statements have been prepared for placing before the members at the annual general meeting of the society for the purpose of fulfilling the Council's financial reporting requirements under its Rules.

Our audit has been conducted in accordance with Australian Auditing Standards to provide reasonable assurance as to whether the financial statements are free of material misstatement. Our procedures included examination, on a test basis, of evidence supporting the amounts and other disclosures in the financial statements, and the evaluation of accounting policies and significant accounting estimates. These procedures have been undertaken to form an opinion whether, in all material respects, the financial statements are presented fairly in accordance with Australian accounting standards so as to present a view of the society which is consistent with our understanding of its financial position and the results of its operations and cash flows.

The audit opinion expressed in this report has been formed on the above basis.

Audit Opinion
In our opinion the financial report presents fairly the financial position of The Royal Society of New South Wales as at the 31 December 1996 and the results of its operations and its cash flows for the year ended in accordance with such Accounting Standards as have been applied tot he extend described in note 1 to the financial statements.

(Original signed by Alan Puttock)

WYLIE & PUTTOCK
Chartered Accountants
ALAN M PUTTOCK

189 Kent Street
SYDNEY NSW 2000

BALANCE SHEET AT 31 DECEMBER 1996

1995		NOTE	1996
	CURRENT ASSETS		
4008	Cash	2	9745
6002	Receivables	3	5318
4883	Investments	5	183
0	Inventories	4	0
280	Other	4	400
15173	**TOTAL CURRENT ASSETS**		15646
	NON-CURRENT ASSETS		
0	Receivables		0
128872	Investments	5	132760
0	Inventories		0
17145	Property, plant & equipment	6	16491
0	Intangibles		0
146017	**TOTAL NON-RECURRENT ASSETS**		149251
161190	**TOTAL ASSETS**		164897
	CURRENT LIABILITIES		
411	Creditors and borrowings		3927
0	Provisions		0
2258	Other	8	2228
2669	**TOTAL CURRENT LIABILITIES**		6155
	NON-CURRENT LIABILITIES		
0	Creditors and borrowings		0
0	Provisions		0
71	Other	8	55
71	**TOTAL NON-CURRENT LIABILITIES**		55
2740	**TOTAL LIABILITIES**		6210
158450	**NET ASSETS**		158687

BALANCE SHEET AT 31 DECEMBER 1996 (CONT.)

1995		NOTE	1996
	EQUITY		
7311	Library Reserve		7311
10170	Library fund	9	10739
21535	Trust funds	10	22350
119434	Other accumulated funds		118287
158450	**TOTAL EQUITY**		158687
	Capital and leasing commitments	17	
	Contingent liabilities	18	

(Signed)
K.L. GROSE
President

(Signed)
D.J. O'CONNOR
Hon. Treasurer

ACCUMULATED FUNDS ACCOUNT

For the year ended 31 December 1996

1995		NOTE	1996
(2014)	Operating surplus (deficit)		(1147)
828	Donations and interest to library fund	10	569
(1186)			(578)
120862	Accumulated funds at the beginning of the financial year		119434
586	Transferred from library fund	10	0
120262			118856
828	Transferred to library fund	10	569
119434	Accumulated funds at end of the financial year		118287

STATEMENT OF CASH FLOW

For the year ended 31 December 1996

1995		NOTE	1996
	CASH FLOWS FROM OPERATING ACTIVITIES		
11280	Members subscriptions and donations		11018
11171	Other revenue sources		13264
7437	Interest received		9826
(34357)	Administration and other operating expenses		(29183)
(4469)	Net cash provided by (used in) operating activities	18	4925
	CASH FLOW FROM INVESTING ACTIVITIES		
5391	Net reduction in investments		812
(599)	Purchase of office equipment		0
4792	Net cash provided by investing activities		812
323	**NET INCREASE (DECREASE) IN CASH HELD**		5737
3685	Cash at the beginning of the financial year		4008
4008	**CASH AT THE END OF THE FINANCIAL YEAR**		9745

The accompanying notes form part of these financial statements.

NOTES TO AND FORMING PART OF THE ACCOUNTS

For the year ended 31 December 1996

1 SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

These financial statements are a special purpose financial report prepared for use by the council and members of the Society. The council has determined that the Society is not a reporting entity, and therefore there is no need to apply Accounting Standards and other mandatory professional reporting requirements in the preparation and presentation of these statements.

Certain Accounting Standards have been adopted where considered appropriate by the council in the preparation of these statements to the extent indicated in the following notes.

Set out hereunder are the significant accounting policies adopted by the Society in the preparation of these statements for the year ended 31 December 1996. Unless otherwise stated, such accounting policies were also adopted in the preceding year.

(a) Basis of Accounting

The statements are prepared on an accruals basis and are based on historical costs. The statements do not take into account changing money values or, except where specifically stated, current valuations of non-current assets.

(b) Non-Current Investments

Investments are brought to account at cost. The carrying amount of investments is reviewed annually to ensure it is not in excess of the recoverable amount of investments.

(c) Property, Plant & Equipment

Plant and equipment is brought at cost or at independent valuation, less, where applicable, any accumulated depreciation or amortisation.

The depreciable amount of all fixed assets is depreciated over their useful lives commencing from the time the asset is held ready for use.

The exception to the above policy is the society's library which is brought to account at its 1936 independent valuation, a more recent valuation not being available.

(d) Comparative Figure

When required by Accounting Standards comparative figures have been adjusted to conform with changes in presentation for the current financial year.

1995		1996
	2 CASH	
	Included in cash are:	
68	Cash on hand	64
3940	Cash at bank	9681
4008		9745
	3 RECEIVABLES	
	Included in Current Receivables are:	
1645	Membership subscriptions in arrears	2054
1645	Less provision for doubtful debts	2054
0		0
2662	Debtors for contributions towards printing Journal and Proceedings	1986
3340	Other debtors	3332
6002		5318
	4 OTHER ASSETS	
	Included in Current Other Assets are:	
280	Prepayments	400
	5 INVESTMENTS	
	Included in Current Investments are:	
4883	Deposits at call	183
	Included in Non-Current Investments are:	
128872	Interest bearting deposits	132759
	6 PROPERTY PLANT AND EQUIPMENT	
	Included in Property, Plant & Equipment are:	
1125	Office equipment and furniture - at cost less depreciation	953
2410	Office equipment - at 1991 valuation less depreciation	1928
13600	Library - at 1936 valuation	13600
10	Pictures - at cost less depreciation	10
17145		16491

7 CREDITORS AND BORROWINGS

1995		1996
	Included in Current Creditors & Borrowings are:	
411	Sundry creditors and accruals	3927

8 OTHER LIABILITIES

1995		1996
	Included in current Other Liabilities are:	
16	Life Members subscriptions prepaid	16
414	Membership subscriptions paid in advance	146
1828	Journal and Proceedings subscriptions paid in advance	2066
2358		2228
	Included in Non-Current Other Liabilities are:	
71	Life members subscriptions prepaid	55

9 LIBRARY RESERVE

1995		1996
7311	Balance at 1 January	7311
0	Movement for year	0
7311	Balance at 31 December	7311

10 LIBRARY FUND

1995		1996
9928	Balance at 1 January	10170
434	Donations and interest	569
10756		10739
586	Library purchases and expenses	0
10170	Balance at 31 December	10739

11 TRUST FUNDS

1995		1996
	Included in the Trust Funds are:	
3534	Clarke Memorial Fund	3018
6854	Walter Burfitt Prize Fund	6788
3620	Liversidge Bequest Fund	3237
7527	Olle Bequest Fund	8107
0	Dr H.G. Douglass Grave Restoration	1200
21535		22350

12 CLARKE MEMORIAL FUND

1995		1996
5000	Capital	5000
	Revenue	
351	Income for year	273
402	Expenditure for year	789
(51)	Surplus (deficit) for year	(516)
(1415)	Balance at 1 January	(1466)
(1466)	Balance at 31 December	(1982)
3534	Total fund capital and revenue	3018

13 WALTER BURFITT PRIZE FUND

1995		1996
3000	Capital	3000
	Revenue	
211	Income for year	529
14	Expenditure for year	595
197	Surplus (deficit) for year	(66)
3657	Balance at 1 January	3854
3854	Balance at 31 December	3788
6854	Total fund capital and revenue	6788

14 LIVERSIDGE BEQUEST FUND

1995		1996
3000	Capital	3000
	Revenue	
210	Income for year	279
544	Expenditure for year	662
(344)	Surplus (deficit) for year	(383)
954	Balance at 1 January	620
620	Balance at 31 December	237
3620	Total fund capital and revenue	3237

15 OLLE BEQUEST FUND

1995		1996
4000	Capital	4000
	Revenue	
281	Income for year	580
531	Expenditure for year	0
(250)	Surplus (deficit) for year	580
3777	Balance at 1 January	3527
3527	Balance at 31 December	4107
7527	Total fund capital and revenue	8107

16 DR H.G. DOUGLASS GRAVE RESTORATION FUND

1995		1996
0	Donations and other revenue	3245
0	Expenditure for year	2045
0	Balance at 31 December	1200

17 CAPITAL AND LEASING COMMITMENTS

1995		1996
0	Capital and leasing expenditure contracted for but *not* already included in the balance sheet	0

18 CONTINGENT LIABILITIES

Nil

19 CASH FLOW INFORMATION

1995		1996
	Reconciliation of net cash provided by operating activities to operating surplus (deficit)	
(2014)	Operating surplus (deficit)	
828	Library fund donations & interest	569
	Non-cash flows in operating surplus	
679	Depreciation	654
	Changes in assets and liabilities	
(2057)	Reduction (increase) in receivables	684
1225	Reduction (increase) in prepayments	(120)
(3240)	Increase (reduction) in unearned revenue	0
259	Increase (reduction) in creditors	3516
113	Increase (reduction) in members subscriptions in advance	238
(438)	Increase (reduction) in trust funds	815
(4469)	Net cash provided by (used in) operating activities	(4925)

DETAILED INCOME AND EXPENDITURE ACCOUNT

For the year ended 31 December 1996

1995		1996
	INCOME	
11245	Membership subscriptions	13351
233	Application fees	128
11478		13479
	Less	
77	Provision for doubtful debts	2078
11401	Total Membership income	11431
9188	Subscriptions and contributions to Journal publication cost	9885
20589	Total membership and journal income	21316
8563	Interest received	8157
470	Sale of reprints	1528
1096	Sale of back numbers	532
55	Sale of other publications	70
6	Donations - general	0
836	Summer school surplus	0
163	Excursion surplus	82
0	Joint venture with City of Sydney Cultural Council	60
0	Monthly meeting surplus	129
288	Other income	65
32066		31939

1995		1996
	EXPENSES	
2630	Accountancy fees	2760
105	Annual Dinner deficit	36
1370	Audit fees	1440
97	Bank charges and government duties	61
300	Branches of the society	0
679	Depreciation	654
316	Entertainment expenses	331
836	Insurance	796
12507	Journal publication & distribution	12709
586	Library expenses	0
120	Miscellaneous expenses	244
474	Monthly Meetings expenses	0
2464	Newsletter printing & distribution	2039
516	Postage	746
888	Printing & stationery	1061
2000	Rent	2000
0	Repairs	25
6828	Salaries	7322
216	Summer school deficit	0
738	Superannuation contributions	397
410	Telephone	465
34157		33086
(2014)	**DEFICIT** for the year	(1147)

CITATIONS FOR AWARDS

THE SOCIETY'S MEDAL FOR 1996

Patricia Mary Callaghan

Patricia Mary Callaghan graduated from the University of Sydney with a Bachelor of Science, majoring in Mathematics and Physics. Later she was awarded a Master of Science by Macquarie University, following formal course work and a thesis on the "Design, Implementation and Assessment of Reader Education Courses for Chemistry Students". She is also an Associate of the Australian Library association, and has a continuing interest in studying philosophy.

After graduating from the University of Sydney, Miss Callaghan gained industrial experience in Australia and in England. Later, she joined CSIRO as a librarian and also spent some time working at the Ministry of Aviation in London. Thereafter, she was librarian at the Aeronautical Research Laboratories in Melbourne and then joined the staff of the Macquarie University Library.

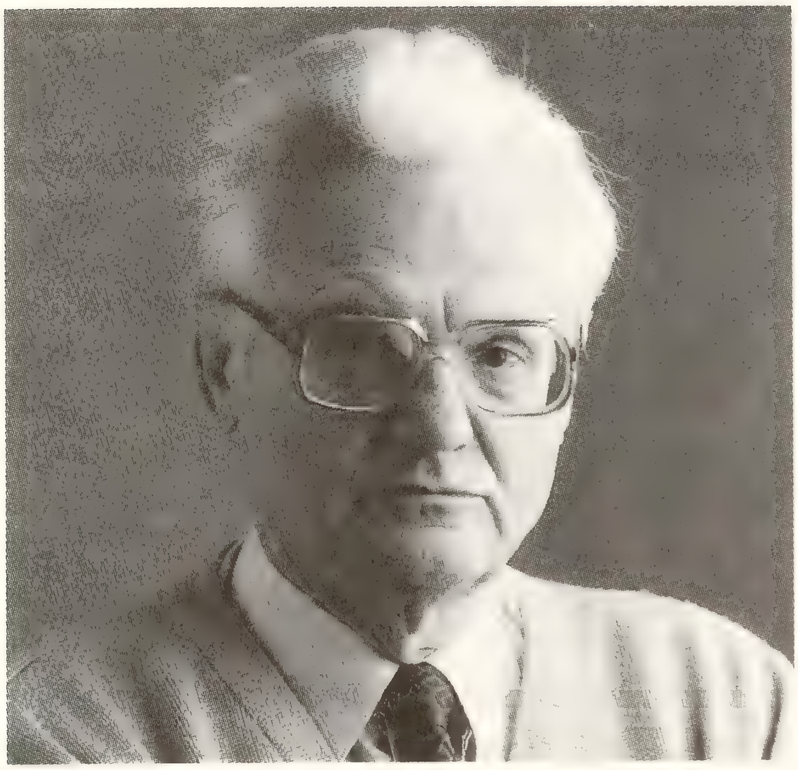
Miss Callaghan has a wide experience of several aspects of library work and in the use of the Dewey Classification System, the Universal Decimal System and the US Library of Congress System. She had a special interest in Reader Education and in cooperation with the School of Chemistry at Macquarie University she helped students in the retrieval and interpretation of chemical data, in the relevance of the literature of analytical chemistry and in the use of the literature of organic chemistry. The results of these original studies were published in three papers, one with the fascinating title of "Beilstein without tears". Her approach stressed the importance of literature reference work for introducing students to the need for critically examining data.

Miss Callaghan has had wide experience in most aspects of library work, including computer searching of a wide range of data bases and teaching the required procedures to postgraduate students. She is the honorary Librarian for the Royal Society of New South wales, a position she has held for the past decade, and is ipso facto a member of the Council. She deals with all aspects of the Society's Collections including exchanges and gifts, and prepares a biannual accession list.

In view of her many achievements in librarianship and of her contributions to the Society, Patricia Callaghan is a very worthy recipient of the Society's Medal for 1996.

THE CLARKE MEDAL (ZOOLOGY) FOR 1996

Professor Klaus Rohde,



Professor Klaus Rohde, is one of Australia's most distinguished zoologists. He has made substantial contributions in several zoological fields after coming to Australia in 1970. After taking his doctorate at University of Munster, Germany, his research has been honed at several institutions including ASTA-Werk A.G, Germany; University of Malaya, Kuala Lumpur; Universitat Bochum, Germany; University of Queensland, Australia; University of Khartoum, Sudan and more lately in Australia at the Heron Island Research station, Queensland and University of New England, Armidale, New South Wales, where he is currently Professor of Zoology.

He is a world leader in several zoological fields, including parasite taxonomy and ecology, zoogeography of parasites and the ultrastructure and phylogeny of Platyheminthes. His work has been published in over 300 scientific journals and has achieved an exceptional citation rate. Major works include his book on "Ecology of Marine Parasites" (1993), a large part of "Diseases of Marine Mammals", Vol. IV (1984) and large reviews contributed to "Advances in Parasitology", Vol.10 (1972), Vol. 13 (1975) and Vol.33 (1994). His work on a range of animal groups and methods of investigation has led to important new evolutionary and ecological insights, related to niche theory and latitudinal gradients in species diversity.

Professor Rohde has gained extensive research grants for his work and has supervised many students, who have also made significant contributions to Zoology in Australia. His work was recognised with the first Vice Chancellor's Award for Excellence in Science at the University of New England, in 1996. He is a most worthy recipient for the Clarke Medal in Zoology for 1996.

THE EDGEWORTH DAVID MEDAL FOR 1996

Dr Peter Alexander Robinson

The Edgeworth David Medal is awarded for distinguished contributions to Australian science by a scientist under the age of thirty five.

Dr Peter Alexander Robinson graduated from the University of Sydney with a Bachelor of Science, First Class Honours and a University Medal. After completing a Doctor of Philosophy degree, he was a Research Associate at the Department of Astrophysical, Planetary and Atmospheric Sciences at the University of Colorado in Boulder. In 1990, he returned to the Department of Theoretical Physics at the University of Sydney as a Queen Elizabeth Research Fellow. He is Currently a Senior Lecturer in this Department. Dr Robinson has received many scholarships and awards, including the Pawsey Medal, and has a very high success rate in gaining grants for research.

Amongst Dr Robinson's major achievements are notable developments in the theory and simulation of stochastic and nonlinear processes in plasmas. He devised the stochastic growth theory of type III solar-radio bursts, and initiated the first detailed statistical theory of strongly nonlinear Langmuir turbulence. He has also carried out research on applications of these two theories, for example, to explain observations of beam-plasma experiments and intense electric fields in space. An imprimatur of the importance of his research is the large number and quality of his publications, and the repeated invitations to lecture overseas.

Dr Robinson is a very good lecturer and continues to develop innovative approaches to undergraduate teaching. His research

supervisory skills can be assessed by the high quality of his Honours, MSc and PhD students. For example, all his Honours students received First Class degrees and three received University medals. He clearly sees a close relationship between research and teaching and the importance of students being taught by an active research worker.

He takes a very active part in what could be termed the administrative aspects of teaching and research. He also carries out various professional activities in connection with his Department, with refereeing for journals and with assessing proposals for research grants. aspects of teaching and research.

It is clear that Dr Robinson is a scientist of great distinction and his career shows a commendable blend of research, teaching and scientific administration. There is no doubt that Peter Alexander Robinson is a most worthy recipient of the Edgeworth David Medal.

BIOGRAPHICAL MEMOIRS

HAROLD OSWALD FLETCHER
26 February 1903 - 3 August 1996

Harold Oswald Fletcher was born in Sydney on 26 February, 1903. In 1918 he commenced work at the Australian Museum, Sydney, as an Office Assistant. He then had the opportunity to transfer to the scientific staff as a trainee in zoology in 1922. A few years later a Department of Palaeontology was formed at the Museum, and he opted for the chance to become a Palaeontologist. He was allowed to attend Geology lectures at the Sydney University 1925-28 but, being unmatriculated, did not graduate. Attending these lectures put him in touch with W.S. Dun from whom he got much practical advice, and brought him into contact with other officers of the New South Wales Geologic Survey of New South Wales.

Harold Fletcher was appointed Curator of Palaeontology in 1941, and in 1956 became Deputy Director of the Australian Museum. Many colleagues commented on his efficiency as Deputy Director, and his amiability made him many friends. He retired in 1967, after forty-eight years service, and was made an Honorary Research Associate of the Museum. The Hall of Fossils, completed and opened just a few months before his retirement, is a fitting monument to his work, and at the time was the first major gallery exhibit created at the Museum in nearly fifty years. From 1937 to his retirement he was also Honorary Palaeontologist to the Geological Survey of New South Wales.

Fletcher's acknowledged expertise resulted in him being invited to give some lectures in Palaeontology at the University of Sydney in 1938, and in 1945-46, during Ida Browne's leave, he gave the full course. He was seconded from the Museum in 1929-31 to join the British, Australian and New Zealand Antarctic Research Expedition (BANZARE) under Sir Douglas Mawson, as Assistant Zoologist. An account of the two voyages of this expedition in 1929-30 and 1930-31 is given by Harold Fletcher in his book "Antarctic Days with Mawson" (published by Angus and Robertson in 1974). In 1933 he was awarded the King's Polar Medal.

In 1939 he was second-in-command and field biologist in the first crossing of the Simpson Desert, on camels, under the leadership of Dr. C.T. Madigan. An account of this expedition is given by Madigan in his book 'Crossing the Dead Heart' (published by Georgian House in 1946). A colour film (of surprisingly good quality) of this historic expedition is held in the University of Sydney Archives.

During World War II Fletcher served in the C.M.F. on the First Australian Anti-Aircraft Battery, seeing some 476 days of active service.

From the early 1930s he made many collecting and research excursions in New South Wales and in outback parts of Australia. In 1952 he organised and led an Australian Museum Expedition to Central and North-West Australia (to which Dr. Ted Rayner of the Geological Survey of New South Wales was seconded and acted as second-in-command). Harold Fletcher also made a collecting excursion in 1966 from Alice Springs

westward into Western Australia via the "Gunbarrel Highway".

One of his most important field trips (in association with Rayner) involved the guarding of the first large slab of fossil fish discovered near Canowindra and excavated prior to its removal to the Museum.

In 1956 he gained his MSc degree at the University of New South Wales and was elected a Fellow of ANZAAS about the same time. He was also elected a Member of the Explorer's Club of New York.

Harold Fletcher was a keen motorist in the early days of car touring, enjoyed both sail and power boating watersports, and in later years enjoyed lawn bowls, and particularly gardening.

He married (Frances) Mollie Higgs, who survives him with a son, Ian, and a daughter, Ann. Harold's children inherited an interest in the Antarctic, both having visited there.

Harold Fletcher joined the Royal Society in 1933 and was a supporter of the geological section before its demise. Most of his scientific papers appeared in "Records of the Australian Museum" and in "Australian Natural History" published quarterly by the Australian Museum. In his last years he was working on the manuscript of a book about the Australian Museum and his expeditions and excursions within Australia.

Harold Fletcher's demise was noted in the official news of the 30th International Geological Congress, held in Beijing at the time of his death in August, 1996. His life epitomises that of many young people of his generation who seized the opportunity to succeed by their own efforts, through hard work, and yet maintained both th ecommon touch and a zest for living a very full, and not uneventful life.

(E.O.R & D.F.B.)

NOEL MACINTOSH GRAY

Noel Macintosh Gray was a Western Australian by birth. He developed an interest in Geology during his undergraduate years at the University of Western Australia and, graduating BSc in early 1948, found that the post-World War II push for National Development had created numerous openings for geologists, at the time mostly in government surveys. He joined the Geological Survey of Western Australia in February 1948 and for the next four years was involved in geological surveys in many, mostly remote locations in that State. He had the good fortune to cooperate with Joe Lord, who was later to become a senior mining industry geologist and ultimately Director of the Geological Survey of Western Australia. His published reports from this period included studies of manganese and iron resources and especially the gold-bearing region around Coolgardie.

In May 1952 Noel resigned from the Geological Survey to accept an appointment with the Sydney Water Board, with which he was to remain until retirement. The first several years of his service for the Water Board were spent dealing with the great variety of geological problems arising from the construction of the Warragamba Dam, not the least being the monitoring of the quality of the aggregate consumed in vast quantities for the massive concrete dam wall and transported to the site by a continuous bucket line from a gravel island in the Nepean River 3 km downstream. In this period he welcomed many geological parties inspecting the project and gave informative talks which were much appreciated by students eager to witness the practical application of geology.

As the Water Board developed plans for future dams, tunnels and large local storage reservoirs, Noel was deeply involved in the assessment of the feasibility of the proposals. He maintained a continuing interest in the Warragamba storage, having persuaded the Board of the wisdom of installing a set of seismographs at suitable distance from it to monitor whether the weight of Lake Warragamba on the earth's crust would stimulate additional tremors (as happened at other large reservoirs) with the risk that their cumulative vibrations might damage the concrete wall or affect its foundation. By 1980 he was

able to state with some confidence that there was no measurable added seismic activity.

Noel Gray was a noteworthy pioneer in the practice of the then new field of Engineering Geology. He joined the Royal Society of New South Wales in 1952, and at his death on 21 January 1996 the Society lost a valued member.

(A.A.D.)

DOROTHY HILL
1907-1997

Dorothy Hill was first and foremost an Australian and a Queenslander. She had a fondness for the U.K., after spending time in Cambridge to study for a PhD, and being elected to a Fellowship in Newnham College. However she never lost her first love of Queensland, and she spent her life forwarding the interests of the State, its University, its sporting achievements, and its general educational welfare.

Of course, she was best known for her work on Palaeozoic corals. For her work in this area, she managed to attract the attention of various local organisations which passed on to fellow citizens the significance of what she was doing for Queensland. My own family, who had no interest in science, knew her name quite well from articles in the newspaper. Geology was a 'natural' for someone so interested in what was going on in such a diverse State, and it was one of her main aims to develop a broad regional picture of its geological structure. It was not surprising that one of her main aims after WW II, was to prepare a 40-mile State map using whatever resources were available. She convinced the Geological Survey to help support a research worker to draw un a map using the newly available RAAF air photographs as a base, and published works, survey reports, old field geologists note books, and even the memories of trips by pensioned off geologists, as 'ground truth'. It was rarely possible to check the interpretations directly, though visitors who had been working in an area were called in to check the interpretations.

As a result of these maps, she began to develop a new interpretation of the State's Geology, and with A.K.Denmead she began to outline a pattern of geological development. She used people from government departments, from industry and from academe to write specialist parts of the text, and fitted it all into an outline that she herself developed. The product of this work was issued as Volume 7(1), Geological Society of Australia.

Although she was primarily a palaeontologist, she also spent time in the field doing basic mapping. Her Honours field work required her to understand the stratigraphy and structure of Mesozoic sediments and volcanics of the Brisbane Valley. This study was published in the Royal Society of Queensland, and forms the basis of most later work in the area. Her interest in corals also came from some work she did at Mundubbera, where she observed a relatively well-exposed Carboniferous coral reef. This material was studied in Cambridge, and it also was published in the Royal Society of Queensland. This led her to study European corals in detail, and provided her with a basis for her life's study when she returned to Australia. Among her later Australian coral work were seven papers published in the Royal Society of NSW. This work established her as a leader in the opening up of Palaeozoic coral palaeontology in the wider areaof Australia. For the breadth of this work

she was elected to give the Clarke Memorial Lecture in 1971, and was made an Honorary Member of the Royal Society of NSW in 1993.

For her, life was not all books and laboratory. While still an undergraduate she was interested in athletics, particularly hurdling and hockey. She won a Blue for hockey. In England she learned to fly, and gained an "A" Class pilot's licence. As a Professor she maintained her interest in student sports, and was Vice-Patron of the Queensland Womens Hockey Association.

She was not noted for her dress sense, and indeed what she wore when giving a public lecture was the last thing she thought about. I remember her telling the story of how she was getting dressed to speak at some important occasion in another state, and then finding that her skirt had no belt. This was an important item with this particular structure, and so she explained that it was difficult to turn the pages of her notes while using her other hand to maintain her dress standards. It seemed unfortunate to her that to appear at a public event required her to spend time on appearances rather than on what she was going to say.

In her profession she held many important posts. She was a Research Professor and then a Full Professor in Geology; Chairman of the Professorial Board; Secretary of the Great Barrier Reef Committee; President of Section C of the ANZAAS; President of the Australian Academy of Science; Fellow of the Royal Society of London.

While she led the Professorial Board during Sir Zelman Cowan's Vice - Chancellorship, some staff and students were actively opposing the administration. She found this process very trying and felt that many problems could be sorted out by more active measures by staff who, after all, supposedly held their positions because of their intellects. She adhered to the view that a University was indeed a place of Light and Learning, and not a place for groups to try to exercise political powers. Light and learning disappeared during revolutions, and one of the main values of Universities was lost. Her work during this period took a great deal of effort and took away from her research time - a dreadful blow to her.

As a teacher she excelled as a person-to-person instructor. My own remembrance of her in this regard relates to her supervision of my honours projects. She had a small grant to study Foraminifera from the Timor area. As I had chosen to study forams for special work, I did some preparation and sorting of the material, as well as preliminary interpretations. Each day she would visit me and would discuss the outcomes, with the result that my rate of learning increased dramatically while trying to keep up with the questions. Later on I was working on Permian brachiopods, a field in which she had no experience. She set about working on a Permian fauna from Cracow in the Dawson Valley, andpublished a small paper on it. She mentioned to me many years later that she undertook that work to aquaint herself with the literature and to see what work needed to be done. As a result she would always have useful enquiries of me during her daily visits. She was a leader in research with her students as well as with her own research.

During the WW II she joined the WRANS, and served as a coding and cipher officer in HMAS Moreton. In this work she gained a capacity to work in authority over incoming vessels. Brisbane was one of the main ports for American support for their troops in Australia. I think that she must have had a rough time with some American seamen, because for many years afterwards she would have little to do with Americans, be they in civil life or in palaeontology. I recall her saying that most useful work came from Europe, and German and British work was almost invariably outstanding. All this changed somewhat when Prof. John Wells of Cornell, made extended visits while preparing the coral volume for the Treatise on Invertebrate Paleontology. He was a man of interest and charm, and he won her over to think more charitably about American work. The Treatise volume was a joint effort between the two of them. Subsequently, she was asked to redo the Paleozoic part of the work in the light of recent developments. Much more work had

been done in the USSR and in China. She published the revision in two volumes; they stand as a model for subsequent work of this kind. She also became interested in Archaeocyathids when asked to work on the Cambrian collections from Antartica. A monograph on this group appeared, and she was asked to prepare a further Volume of the Treatise on that group. She remains the only person who has contributed three volumes to this international publication.

Her work won her several civilian honours. She was awarded a CBE and an AC for her contribution to Australian education, research, administration and sporting achievements.

Above all else, she was a woman of integrity. She stood by her word under all circumstances, a trait that did not equip her to handle the deviousness of political champions in the University. Despite this she had a strong belief in human nature, some of which, unfortunately, was wrongly placed. With all her achievements and her stature in Queensland and Australia as a whole, she was always approachable and friendly to all who came into contact with her. She attracted students by her kindly but serious attention, and was able to bring students into her field of study right up till the last years of her teaching. She has one of the great women scientists and educators this country has produced.

(K.S.W.C)

ANNUAL DINNER ADDRESS

Royal Society of New South Wales,
Wednesday, 12 March 1997

His Excellency the Honourable Gordon Samuels AC Governor of New South Wales.

Mr President, Ladies and Gentlemen. I am delighted to have this opportunity of addressing the Society, of which I have the honour to be a Joint Patron.

The Society's formal invitation touched, in somewhat enigmatic terms, upon the topic which I might select for my address this evening. Your President pointed out that Barron Field, a judge of the Supreme Court of New South Wales, was one of the Society's three founders; and the letter went on to observe that the Society went into a state of dormancy during 1822, "being torn apart in the maelstrom of politics" which James Stephen Jnr termed "the Goulburnian Controversy". To someone such as myself, regrettably languishing in a state of substantial ignorance concerning the antecedents of the Society, this was titillating enough. But Dr. Grose then advised me not to get involved "in this Sargasso Sea", pointing out that both the Society's first President, Sir Thomas Brisbane, and Major Goulburn "first Colonial Secretary of New South Wales" and presumably the eponymous protagonist of the "Controversy" fell victim to it. To a former historian this was powerful temptation. However, the awful nature of the President's warning prevented my falling victim to it, save, perhaps, to a minor degree. The French literary critic, Roland Barthes, has coined a rhetorical figure designated as 'paralypse' which "consists in stating what one is not going to say." This amounts to a solemn covering of one's flanks, a scholarly gesture often adopted by academics in those learned papers which describe, not a second coming but a second going - that is to say, which do not describe a subject matter initially encountered, but rather one revisited[1].

So I may say that I have not attempted to analyse the origins of the "Goulburnian Controversy", or its effect upon the life of the Society, save in the most general way, and then only to indicate the extent of my unsatisfied interest.

There appears to be evidence to suggest that your President's phrase "maelstrom of politics" was, as one would of course expect, well and accurately chosen. Emeritus Professor Elkin in his Centenary Oration to the Society[2] quotes the same Barron Field's observation that the Society "expired in the baneful atmosphere of distracted politics".

But on the same page in Elkin's paper there is a reference to a statement by The Reverend W.B. Clarke. He said, in his Inaugural Address to the Society in 1867, "the fictitious, variable value assigned to the dollar, the coin then prevalent [in 1822], was the cause of the breaking up of the little band who cultivated science for the love of it". This reference raises a variety of conjectures which I cannot allow myself to pursue.

The existence of political conflict of a disruptive kind seems to be the theory adopted by later historians. It is suggested that Brisbane's administration had proved inadequate before his open dissension with Goulburn provided a happy justification for recalling them both, and brought about the suspension of the Society as an unintended consequence[3]. Incidentally, Melbourne (the author) provides in this context an interesting description of the source of the Governors being equipped with both an Official Secretary and a Private (and confidential) Secretary, a practice which has only just been discontinued[4].

The Edinburgh Review[5], more sympathetically and less condescendingly than I would have thought likely, attributes the fracas to disagreement between the emancipists and the exclusives in the early Colony. In the course of treatment rather favourable to the emancipists, the reporter attributes to this struggle the dispersion of "even the Philosophical Society of Australia" and Dr Field's apothegm is adopted.

I must confess that at this stage I had begun to discount your President's warning. I contemplated pursuing what seemed to represent an uncomplicated scholarly adventure, with no more than the ordinary ration of inconsistencies and contradictions. The evidence seemed to support a comfortably plausible explanation of the friction between Brisbane and Goulburn leading inevitably to the disruption of the body of scholars of which they were leading figures. But hubris now received its inevitable deserts. I discovered the theory that attributed the cessation of the Society's activities in 1822 to a clash between the Society's Secretary, Dr Douglass, and other gentlemen, over a female convict[6].

This was a departure indeed from the heady atmosphere of politics and power. It was evident that, running the extreme risk of a terminal mixture of metaphors, I had stumbled into the seaweed. However, since I never intended to discuss the early history of the Society I can obliterate this mis-conceived reconnaissance and shortly address my real topic.

I had thought that there might have been a suggestion in the President's reference to Judge Field that I should talk to you upon a legal topic. And so, while trying not to speculate about what was indeed the cause of the Society's early temporary collapse, I wondered how a scientist on the one hand, and a lawyer on the other, might set about investigating the question.

Assume that the object of the exercise is to find out why the Society ceased to exist in 1822. The question which I suppose one could put to a scientist would be, "What was the cause of the Society's closure in 1822?" That is, or at least it seems to me to be, an invitation to an investigator to seek the truth of the matter - to find out why indeed the event happened. A lawyer, practising in our common law adversarial system, on the other hand, would be less than comfortable with an approach of this kind. Indeed, I think that I dare say that the lawyer would prefer not to be invited to undertake an open ended inquiry. The preference would be to find an issue of some kind in which one party contended and another party denied. Hence, to make the lawyer most comfortable the inquiry would need to be framed, for example, in this way: "Was the conduct of Frederick Goulburn responsible for the closure of the Society in 1822?"

The precise formulation of that issue is not relevant for present purposes. What is important is to see that the kind of inquiry with which the lawyer most often deals, and the methodology adopted, is to determine which of two adverse contentions is correct. Hence, the lawyer would endeavour to amass evidence which was capable of proving,

according to some measure or standard of proof, that the assertion of the claimant, that Goulburn did cause the fall of the Society, was correct.

You will appreciate the manner in which the two methods differ. You will no doubt observe the basic dichotomy between them. Scientific method entails an inquiry into the truth; legal method seeks to produce a winner.

You will also, of course, have noticed that the adoption of the legal rather than the scientific method has another innocent advantage. Legal method requires two lawyers, one to assert and one to deny. However, you need only one scientist to find the truth.

Thus I think it is true to say that scientific inquiry is designed to ascertain the truth, whereas legal inquiry is not. But that is not to say that scientific inquiry ascertains the truth, whereas legal inquiry does not. Some scientists would argue that it is impossible to advance an affirmative scientific proposition which one can call true. Karl Popper put the matter thus[7]: "When we think we have found an approximation to the truth in the form of a scientific theory which has stood up to criticism and to tests better than its competitors, we shall, as realists, accept it as a basis for practical action, simply because we have nothing better (or nearer to the truth). But we need not accept it as true: we need not believe in it (which would mean believing in its truth)".

On the other hand, the classic adversarial trial by dint of powerful statements on each side of the question may very well ascertain the truth. So the scientist seeks, but may not find. The lawyer collects an unsought bonus.

I appreciate that matters of this kind are generally regarded as pertaining more to the sphere of medico-legal societies or societies which are dedicated to the discussion of forensic science and its problems. However, the standards of scientific research and the integrity of scientific method are matters of great importance to our community, which depends more and more upon the results (and the accurate transmission) of scientific investigation into the many problems which threaten us.

May I add one thing more. The aims of the Society described in its Rules[8] are "to encourage studies in Science, Art, Literature and Philosophy ..."[9]. It seems that the Society has confined itself to Science[10]. I cannot myself see any evidence to the contrary - until tonight perhaps! Might it not be time to consider relaxing this orthodoxy? I would not suggest trafficking with lawyers - that would be too latitudinarian a step! But, if such an initiative has not already been undertaken, consideration might be given to the History and Philosophy of Science.

I thank you for your patience. I hope that I have not abused such privileges as patronage confers.

REFERENCES

1 Updike, *Hugging the Shore* (Andre Deutsch 1984) p 587.

2 Elkin, *The Challenge to Science*, 1866; *The Challenge of Science*, 1966, Centenary Oration to The Royal Society of New South Wales, 28 October 1966 at pp 13,14.

3 Journal of the Royal Australian Historical Society 1977, Vol 61, pt. 3, p. 147; Melbourne, *Early Constitutional Development in Australia*, 1963 pt. II Ch 1 pp 104-6.

4 Melbourne, ibid, p 104.

5 January, 1828, pp 94-7.

6 Branagan, *Words, Actions, People: 150 Years of the Scientific Societies in Australia*, Journal & Proceedings, Royal Society of New South Wales, 1972, Vol. 104, pp 123-141; Australian Dictionary of Biography, Vol. 1, p 314).

7 *Unended Quest*, Fontana-Collins Ed. 1976, p 151.

8 Royal Society of New South Wales Rules, (1968 Ed).

9 *Ibid*, Clause 1.

10 Elkin, loc cit p 28.

NOTICE TO AUTHORS

A "Style Guide" to authors is available from the Honorary Secretary, Royal Society of New South Wales, PO Box 1525, Macquarie Centre, NSW 2113, and intending authors should read the guide before preparing their manuscript for review. The more important requirements are summarised below.

GENERAL

Manuscripts should be addressed to the Honorary Secretary (at address above). Manuscripts submitted by a non-member must be communicated by a member of the Society.

Each manuscript will be scrutinized by the Publications Committee before being sent to an independent referee who will advise the Council of the Society on the acceptability of the paper. In the event of rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere nor is likely to be published substantially in the same form elsewhere. Well-known work and experimental procedure should be referred to only briefly, and extensive reviews and historical surveys should, as a rule, be avoided. Letters to the Editor and short notes may also be submitted for publication.

Original papers or illustrations published in the Journal and Proceedings of the Society may be reproduced only with the permission of the author and of the Council of the Society; the usual acknowledgements must be made.

PRESENTATION OF INITIAL MANUSCRIPT FOR REVIEW

Two, single sided, typed copies of the manuscript (double spacing) should be submitted on A4 paper.

A manuscript should be arranged in the following order: title; names(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgements; appendices; references; names of Institution/Organisation where work carried out/or private address as applicable. Captions to illustrations should be prepared on a separate sheet and a table of contents should also accompany the paper for the guidance of the Editor.

Spelling follows "The Concise Oxford Dictionary". The Système International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigaphic names must conform with the International Stratigraphic Guide and must first be cleared with the Central Register of Australian Stratigraphic Names, Australian Geological Survey Organisation, Canberra, ACT 2601, Australia.

The **Abstract** should be brief and informative.

Tables should be adjusted for size to fit the final publication, and should be numbered serially with Arabic numerals and must have a caption.

When submitting a paper for consideration, all **Illustrations** should be in the form and size intended for insertion in the master manuscript. If this is not readily possible then an indication of the required reduction (such as reduce to $^1/_2$ size) must be clearly stated.

Diagrams, Graphs, Maps and Photographs must be numbered consecutively with Arabic numerals in a single sequence and each must have a caption. Maps, diagrams and graphs should generally not be larger than a single page. However, larger figures can be printed across two opposite pages.

The **Scale** of maps or diagrams *must* be given in bar form.

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Heavy Metals in Ceiling Dust of Some Sydney Houses, New South Wales, Australia

C.L. WHICKER, W.J. HAYES, C.S. KHOO & R.S. BHATHAL

ABSTRACT. The levels of selected heavy metals (Pb, Cu, Zn and Cd) in ceiling dusts from buildings in south-western Sydney were determined. Concentrations ranged from 165 to 2490 μg g^{-1}, 57 to 517 μg g^{-1} and 97 to 3664 μg g^{-1} for lead, copper and zinc respectively. Despite high variability, the levels regularly exceeded the recommended guidelines for identification of contaminated soils. Cadmium was not detected in any sample. Lead was significantly higher in older buildings (>15 years) located in heavily developed areas. This difference was expected for copper and zinc as well, however, large variabilities made these comparisons less distinct. All sites displayed remarkably similar particle size distribution. The patterns of metal loading were also similar, with metal levels rising as particulate size decreased. The fine particulate matter (<106 μm) was noticeably metal enriched, especially in lead. Given that the fines may account for more than half the ceiling dust mass, the atmosphere is thus a significant contributor of particulate matter and associated heavy metals to domestic environments in this region.

Keywords: heavy metals, dust, fractionation, Sydney.

INTRODUCTION

Dust in and around the home has long been identified as a major source of heavy metals in humans (Charney *et al.*, 1980; Rutter & Jones, 1983; Fergusson *et al.*, 1986; Fishbein, 1989; Hunt *et al.*, 1992). For example, Charney *et al.* (1980) identified a strong correlation between the lead content in household dusts and elevated blood lead levels in children exposed to such dusts. In a study of houses in Christchurch, New Zealand, Fergusson *et al.* (1986) found enrichment of lead, copper, arsenic, zinc, cadmium, cobalt, antimony and chromium in dust samples compared with the levels in surrounding soils.

Metal-laden house dusts are derived from contaminated soil, motor vehicle emissions and the fine particulate matter resulting from the degradation of paints and road surfaces (Hunt *et al.*, 1992). They are conveyed into dwellings by humans (or other animals) and atmospheric deposition. While no one particular source necessarily represents the principal contributor of metals, it is clear that the type of surrounding environment influences the overall content. For instance, from a comparative study of dusts sampled from houses located in rural, suburban and industrial areas, Krause *et al.* (1987) identified that the levels of lead

increased from rural to suburban to industrial, highlighting the significance of atmospheric sources. Duggan & Williams (1977) reported similar results for street dusts.

Previous studies have involved sampling of the living spaces of residential buildings, concentrating on carpet and floor areas. Such areas would mainly contain dusts originating from soil, paint fragments and animal conveyed matter. The authors are unaware of any publication specifically investigating the metal levels in dusts taken from ceilings. Such samples may better reflect the contribution of metals by the atmosphere, especially lead, given that petrol combustion and evaporation accounts for up to 90 percent of the dust lead in urban areas (Waldron, 1980; Fergusson & Schroeder, 1985). For Australian domestic buildings, most are covered by terracotta or concrete roof tiles which allow air flow through the roof. This air flow is responsible for the transportation of dust and other foreign materials into the roof cavities.

This study examined the levels of four common heavy metals (lead, copper, zinc and cadmium) in ceiling dusts of buildings in south-western Sydney. Samples were collected by vacuum suction from eleven residential locations in the Campbelltown district, six of which are heavily developed (here classified as 'urban' sites) and five only moderately so (here classified as 'sub-urban' sites).

The six urban sites (sites 3-8) are located in the suburb of Campbelltown itself, all being close to main roads (within 100 metres). Two are houses (Lindesay Street (1) and Hoddle Avenue; both 40-43 years old) and four are separate buildings of a primary school (Lindesay Street (2)-(5); 80, 42, 35 and 25 years old, respectively). The five sub-urban sites are located in the suburbs of Raby (sites 1, 9-11) and Leumeah (site 2). The Raby sites consist of four houses (Bristol Avenue, Lockheed Street, Siddeley Place and Skyhammer Place; 13,13,13 and 2 years old, respectively). The Leumeah site (Brudenell Avenue) is a 28 year old house. Each building has tile roofing, except the oldest two (sites 5 and 6), for which both have a roof constructed of zinc-galvanised corrugated iron. The total concentrations of lead, copper, zinc and cadmium in the samples were determined by flame atomic absorption spectrophotometry. Fractionation studies were also performed to establish which particle sizes contained the highest proportions of metal.

MATERIALS AND METHODS

Sampling

Despite there being no standard technique for dust sampling (Sutton *et al.*, 1995), the recommended procedure is to collect by vacuuming, provided careful cleaning of the apparatus is performed between each individual sample (Mata *et al.*, 1994). This was the method employed here.

Dust was collected by vacuum suction (using an Electrolux™ model Z335 700W vacuum cleaner) through plastic tubing into a specially constructed Perspex filter trap. For each sample a horizontal area of approximately 0.5m^2 was covered. The dust was immediately transferred to a plastic specimen container and the sampler was thoroughly cleaned before next use. All plasticware that came into contact with dust was washed in dilute nitric acid.

Each site was sampled at three separate areas of ceiling, one each from the front, middle and back. Total metal analysis was performed in duplicate on each sample, enabling an assessment of within-site variability, as well as between-site

variability. The three site replicates were then combined prior to the fractionation studies.

Heavy metal analysis

To an accurately weighed portion of dust (approximatelv 0.5 g) were added 20 mL of a 6:1 solution of concentrated nitric and perchloric acids. The mixture was heated at 250°C to dryness, then dissolved in the minimum quantity of 1% v/v hydrochloric acid and diluted to 100 mL with Milli-Q (i.e. reverse osmosis purified) water. The sample solution was then filtered through a Whatman 5B filter paper into an acid-washed specimen container. Metal concentrations (Pb, Cu, Zn, Cd) were determined using a Varian Techtron Spectra AA-20 flame atomic absorption spectrophotometer (Varian Australia, Victoria, Australia).

Fractionation analysis

The entire site-composite dust was passed through a set of seven Endecotts stainless steel sieves using an Endecotts EFL2 mk3 Test Sieve Shaker (Endecotts Ltd, Lombard Road, London SW19 3BR, England). Shaking time was set at 15 minutes and the resulting fraction size ranges were as follows:

Fraction 1	=	> 425	µm
Fraction 2	=	250 - 425	µm
Fraction 3	=	180 - 250	µm
Fraction 4	=	150 - 180	µm
Fraction 5	=	106 - 150	µm
Fraction 6	=	75 - 106	µm
Fraction 7	=	53 - 75	µm
Fraction 8	=	< 53	µm

Two accurately weighed sub-samples of each fraction were then digested and analysed for their total heavy metal content as described previously. The final filtration step was not performed, however, since tests with three randomly selected digests indicated there was no difference in the spectrophotometer reading between filtered and unfiltered solutions. A Varian SpectrAA-200 flame atomic absorption spectrophot-ometer (Varian Australia, Victoria, Australia) was used.

Quality Control

All reagents were analytical grade, or better. Working standards for AAS were prepared from 1000 ppm stock solutions, made by dissolving BDH solid lead nitrate, copper sulfate, zinc sulfate and cadmium chloride reagents (BDH-Merck, Victoria, Australia) in 10% nitric acid. Suitable numbers of sample blanks were analysed, following the recommendations of Rothery (1986), and analytes in these blanks were consistently below 0.05 mg L^{-1}.

The USEPA certified RTC Baghouse Dust CRM014-050 reference material (Resource Technology Corp., Laramie, Wyoming; purchased from Graham B. Jackson Pty Ltd, Dandenong, Victoria, Australia) was co-analysed. This standard reference material has certified levels for lead and cadmium. The mean percentage recovery results for seven replicates were 95.4 (with 12.5% RSD) and 92.9 (with 5.5% RSD), respectively.

Statistical analysis

All statistical analyses were conducted using SYSTAT 5.2 (Wilkinson, 1992). Where necessary, reference was made to the text of Sokal and Rohlf (1969). Data were grouped on the basis of sitetype (i.e. urban or suburban) and building age (<15 years, 15-35 years and >35 years) to assess differences.

Site	Site Location	Site type	Lead (μg g^{-1})	Copper (μg g^{-1})	Zinc (μg g^{-1})
1	Bristol Avenue, Raby	sub-urban	445 ± 141	106 ± 23	1422 ± 1195
			(297 - 578)	(80 - 120)	(495 - 2771)
2	Brundall Avenue, Luemeah	sub-urban	619 ± 81	104 ± 11	247 ± 69
			(529 - 685)	(97 - 117)	(176 - 313)
3	Hoddle Avenue, Campbelltown	urban	602 ± 30	387 ± 108	692 ± 150
			(574 - 654)	(258 - 517)	(536 - 919)
4	Lindesay Street (1), Campbelltown	urban	797 ± 100	70 ± 0	1087 ± 436
			(712 - 907)	(79 - 79)	(673 - 1542)
5	Lindesay Street (2), Campbelltown	urban	11763 ± 845	90 ± 16	3044 ± 527
			(594 - 2490)	(71 - 109)	(2446 - 3664)
6	Lindesay Street (3), Campbelltown	urban	1133 ± 273	118 ± 19	2561 ± 1013
			(868 - 1463)	(95 - 136)	(1216 - 3530)
7	Lindesay Street (4), Campbelltown	urban	1061 ± 647	180 ± 58	351 ± 93
			(560 - 1894)	(113 - 236)	(263 - 483)
8	Lindesay Street (5), Campbelltown	urban	1100 ± 225	164 ± 80	377 ± 94
			(776 - 1317)	(58 - 264)	(273 - 509)
9	Lockheed Street, Raby	sub-urban	592 ± 314	124 ± 52	224 ± 135
			(214 - 1042)	(57 - 159)	(97 - 424)
10	Siddley Place, Raby	sub-urban	583 ± 89	98 ± 32	170 ± 23
			(484 - 657)	(78 - 135)	(155 - 196)
11	Skyhammer Place, Raby	sub-urban	524 ± 622	91 ± 33	535 ± 242
			(165 - 1768)	(69 - 155)	(214 - 828)
	All sites		822 ± 491	150 ± 103	1027 ± 1105
			(165 - 2490)	(57 - 517)	(97 - 3664)

(μg g^{-1}) = micrograms metal per gram of dust.
Values in brackets are the observed minima and maxima.

Table 1. Heavy metal means, standard deviations and ranges for ceiling dusts collected from the eleven sites in the Campbelltown district.

RESULTS AND DISCUSSION

Total heavy metal concentrations

Site means, standard deviations and ranges for lead, copper and zinc are listed in Table 1. For all samples the concentration of cadmium was below the detectable limit (< 1 μg g^{-1}). The means for all sites combined are relatively similar to those from a study of twelve houses in Christchurch, New Zealand (Fergusson *et al.*, 1986), in which the house dust lead, copper and zinc values were 734±398 μg g^{-1}, 230±91.1 μg g^{-1} and 845±186 μg g^{-1}, respectively.

Large standard deviations and ranges

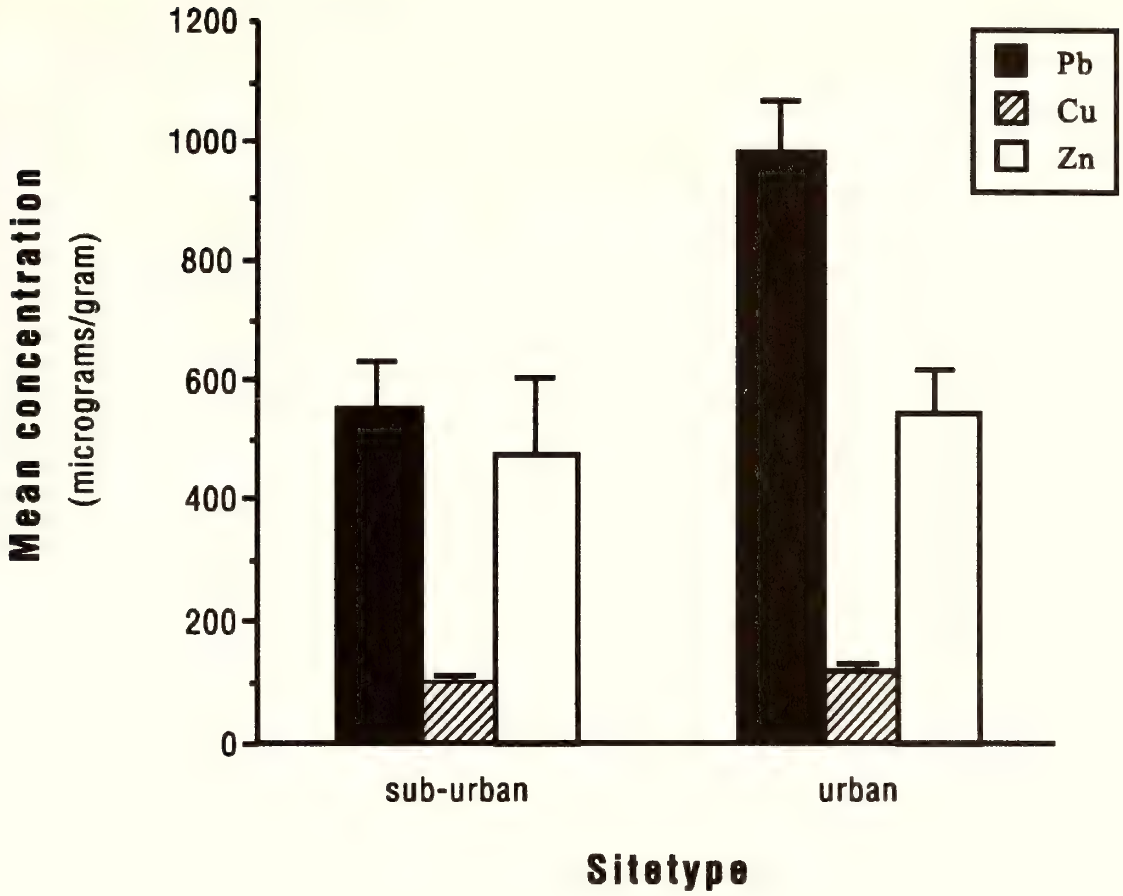

Fig.1. Mean heavy metal concentrations for the urban and sub-urban Campbelltown sites. (Error bars are the standard errors; copper data for site 3, and zinc data for sites 5 and 6 omitted).

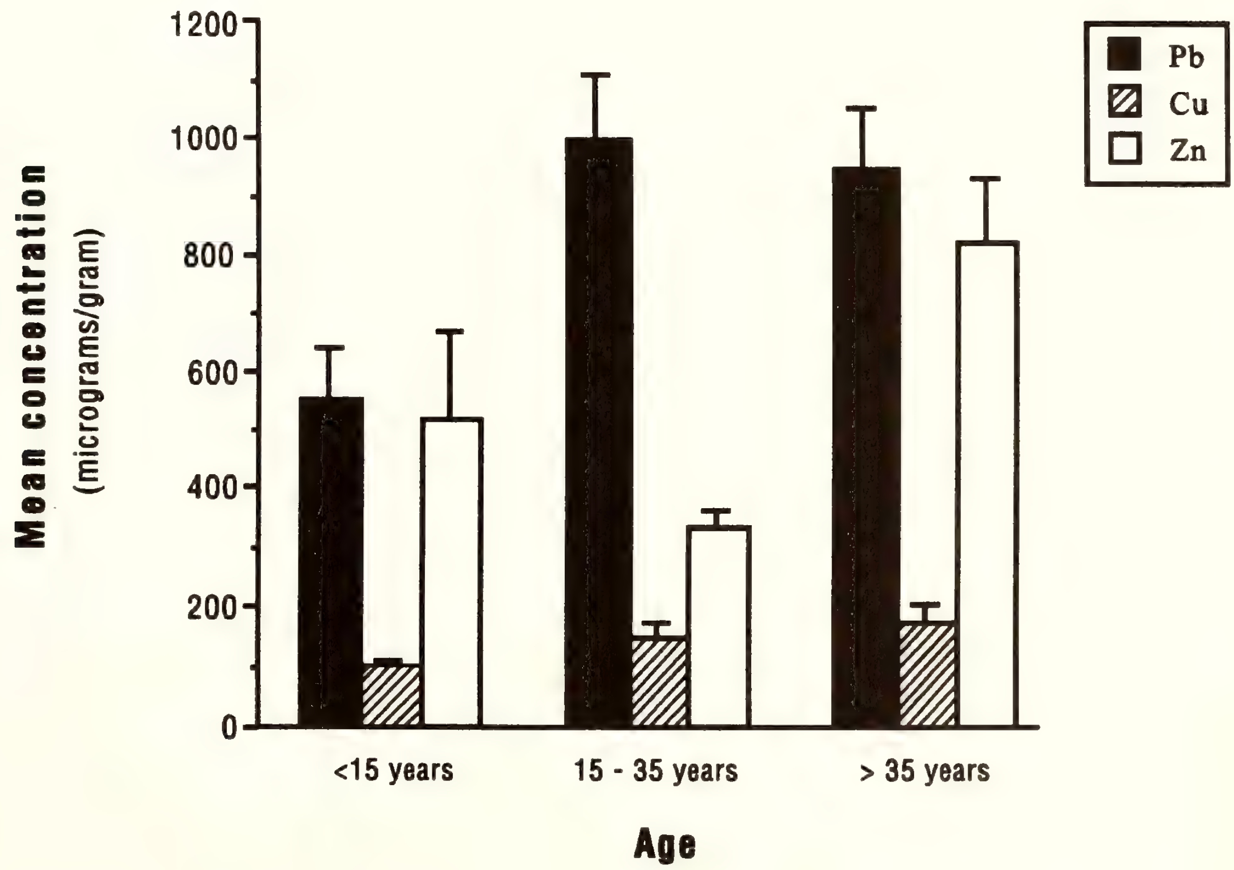

Fig. 2. Mean heavy metal concentrations for the Campbelltown sites, as grouped by building age. (Error bars are standard errors; zinc data for sites 5 and 6 omitted).

Site	Fraction 1 >425 µm	Fraction 2 250-425 µm	Fraction 3 180-250 µm	Fraction 4 150-180 µm	Fraction 5 106-150µm	Fraction 6 75-106µm	Fraction 7 53-75µm	Fraction 8 <53µm
1	26.35	8.53	6.89	2.69	7.19	10.18	12.13	26.05
2	40.61	4.44	5.63	1.47	5.58	8.85	10.37	23.05
3	12.20	6.46	5.98	3.09	6.73	12.02	13.98	39.54
4	14.90	10.87	12.14	2.39	9.79	15.66	13.63	20.62
5	27.29	7.81	8.85	3.08	5.38	9.80	12.41	25.38
6	10.83	4.59	5.44	2.81	8.20	14.37	16.70	37.06
7	7.27	4.00	5.21	3.19	8.94	16.84	19.35	35.20
8	37.10	8.96	5.58	2.71	7.30	11.15	9.80	17.40
9	11.88	7.31	7.31	2.35	4.96	8.49	11.62	46.08
10	19.50	7.09	7.98	1.77	6.74	11.88	10.82	34.22
11	15.45	7.43	7.08	3.18	6.96	10.50	10.61	38.80
Mean	**20.31**	**7.04**	**7.10**	**2.61**	**7.07**	**11.79**	**13.86**	**31.22**
Stand. Dev.	**11.09**	**2.09**	**2.03**	**0.57**	**1.48**	**2.75**	**2.93**	**9.15**

Table 2. Relative percentages by weight following ceiling dust fractionation for the eleven study sites.

were observed for the sampling sites, especially for lead and zinc, indicating considerable within-site metal heterogeneity. This was consistent with the wide range of particle sizes and types present in each sample, clearly observable by eye. Despite such variabilities, values were regularly greater than the environmental soil quality guidelines suggested by the Australian and New Zealand Environment and Conservation Council / National Health and Medical Research Council (1992). Some 89% of all lead concentrations exceeded the 300 µg g^{-1} guideline, while for copper and zinc the proportion of values in excess of the corresponding 60 µg g^{-1} and 200 µg g^{-1} guidelines were 94% and 87%, respectively.

Mean lead levels in dusts from the four primary school buildings (sites 5-8) were particularly high, ranging from 1061 to 1163 µg g^{-1}. Mean zinc levels in the first two of these sites were also elevated (3044 and 2561 µg g^{-1}, respectively), probably a consequence of the galvanised metal roofing (Kim and Fergusson, 1993). Such high levels in these school buildings highlights a possible public concern, considering the regular inhabitants are young children.

Upon grouping the raw data by sitetype, lead concentrations were clearly higher in ceiling dusts collected from the heavily developed (i.e. urban) sites, compared with the less (and more recently) developed sites. Analysis of variance detected a highly significant probability value of 0.001. For copper and zinc, differences were less distinct due to non-homogeneous sample variances. The mean copper level for the urban sites

(i) Lead

Site	Fraction 1 >425 μm	Fraction 2 250-425 μm	Fraction 3 180-250 μm	Fraction 4 150-180 μm	Fraction 5 106-150μm	Fraction 6 75-106μm	Fraction 7 53-75μm	Fraction 8 <53μm
1	448±70	288±25	333±48	405±14	462±41	537±10	567±17	562±1
2	347±55	424±31	498±15	519±3	558±6	613±0	646±11	616±3
3	409±7	388±112	593±120	793±46	578±5	876±75	927±26	908±127
4	875±45	831±22	868±10	851±57	811±7	782±12	789±13	906±5
5	764±109	761±23	555±73	751±128	882±20	748±8	736±8	746±5
6	604±76	1157±79	1094±352	1141±88	998±12	663±48	825±3	918±36
7	522±44	415±4	546±31	587±30	611±69	773±10	914±24	1349±54
8	584±74	685±12	907±102	1155±24	1204±27	1360±55	1371±69	1875±104
9	461±199	186±63	253±74	240±38	437±8	660±17	725±43	844±18
10	336±10	216±39	538±147	403±41	507±86	575±46	682±39	678±2
11	67±9	223±160	100±27	376±293	174±21	195±3	235±24	417±9

(ii) Copper

Site	Fraction 1 >425 μm	Fraction 250-425μm	Fraction 3 180-250 μm	Fraction 4 150-180 μm	Fraction 5 106-150 μm	Fraction 6 75-106 μm	Fraction 7 53-75 μm	Fraction 8 <53 μm
1	55±2	40±4	48±3	70±8	27±5	66±6	82±9	91±0
2	50±3	60±1	70±8	83±17	75±3	87±8	94±1	115±1
3	547±266	1364±616	1921±889	1517±227	1123±581	742±31	417±21	309±12
4	62±8	641±3	62±1	74±5	72±4	78±6	85±2	116±3
5	16±9	21±0	66±70	49±0	63±9	59±11	74±1	81±1
6	34±3	33±7	38±9	66±11	59±7	49±6	72±6	91±3
7	74±30	76±5	102±3	129±41	135±35	112±8	108±1	135±0
8	53±10	68±8	151±29	155±1	140±0	149±6	133±5	157±8
9	23±1	22±5	58±50	59±6	81±8	109±4	114±4	169±0
10	46±6	39±4	44±12	72±5	70±7	70±7	84±6	88±2
11	20±5	15±3	25±1	33±16	40±8	49±1	65±3	1625±10

Table 3. Metal concentrations in the ceiling dust fractions for the eleven study sites (values in μg metal per gram of fraction): (i) Lead, (ii) Copper, (iii) Zinc - next page.

(iii) Zinc

Site	Fraction 1 >425 µm	Fraction 2 250-425 µm	Fraction 3 180-250 µm	Fraction 4 150-180 µm	Fraction 5 106-150µm	Fraction 6 75-106µm	Fraction 7 53-75µm	Fraction 8 <53µm
1	1021±584	4338±3214	2527±1461	2262±547	1396±124	1074±72	937±3	802±10
2	450±89	770±71	808±26	755±39	740±35	734±13	712±4	632±13
3	2441±736	2513±556	2566±702	3279±33	2877±1017	2837±51	2521±347	2566±126
4	1395±107	2280±93	2177±159	2266±277	1454±90	1207±40	1073±17	1061±14
5	3968±535	8432±779	7120±880	9289±1924	16025±7484	6474±477	4845±50	3719±17
6	5017±1337	9379±1489	8600±2563	8288±563	6074±52	3383±418	2932±29	2506±67
7	389±8	362±16	431±24	492±21	522±8	618±35	656±20	721±13
8	375±8	996±132	1072±269	1283±11	1099±74	886±37	964±49	938±3
9	118±53	144±4	193±28	187±25	281±6	384±2	373±7	355±7
10	270±54	473±331	363±28	867±8	774±114	564±54	595±35	514±1
11	90±14	353±3	549±196	901±192	830±125	661±90	560±35	786±8

Table 3. (cont.)

was heavily influenced by site 3, which displayed an extreme level (387 µg g^{-1}), probably arising from the recent installation of copper piping for a water heating system. If this site were omitted from the ANOVA, a probability value of 0.086 is evident. The mean zinc level for the urban sites was heavily influenced by sites 5 and 6. When the ANOVA for zinc was repeated after omitting these corresponding data, a probability value of 0.576 was generated. Fig. 1 illustrates the observed sitetype means (with copper and zinc data omitted as indicated above).

If the data were grouped by building age, analysis of variance detected a significant difference for lead ($p=0.010$), both the 15-35 years and >35 years sites displaying higher levels than the <15 years sites. No significant difference between these age groups was detected for copper ($p=0.067$). For zinc, significant probabilities were detected, however, the group variances were highly heterogeneous, even when the data for sites 5 and 6 were omitted ($p=0.043$) and log transformations were performed ($p=0.004$). Nevertheless, the mean for the >35 years sites was largest, while mean for the 15-35 years sites was lowest. Fig. 2 compares the observed age group means.

Assessing the level of association between building age and mean lead concentration, a Spearman correlation coefficient of 0.828 was observed. This coefficient was greater than the corresponding critical value at the 0.005 level (0.800). Coefficients of -0.000 and 0.602 were observed for copper and zinc, respectively. No significant association was observed for these two metals (although zinc came close at the 0.05 level, the critical value being 0.618).

It is clear that lead concentrations will be high in the ceiling dusts of older buildings located in heavily developed urban areas. These results reflect those of Sutton *et al.* (1995) who analysed a large number of

house dusts from three urban communities of California. Lead levels of up to 9537 $\mu g\ g^{-1}$ were detected and age of housing was reported as the best indicator of lead concentration.

In the present study, the factors of sitetype and age cannot be completely resolved (i.e. they are confounded) as all the sub-urban buildings are in the <15 year category (except Site 2). Indeed it is difficult to find recently (<15 years) constructed buildings in heavily developed areas of Campbelltown (or indeed in any major metropolitan area). Sub-urban regions often represent areas that are still undergoing development.

Only data from the Lindesay Street sites (i.e. sites 4-8) could be used to assess the relative importance of these two factors. ANOVA, after grouping on the basis of age, generated a probability value of 0.990 for lead, indicating no significant difference between the sub-groups. This would suggest siteype as being more important; however, this conclusion is weak since none of these sites is less than 15 years old.

As there was no significant correlation between the metals themselves, it is likely they originated from different atmospheric sources. Given the findings of Waldron (1980), Fergusson & Schroeder (1985) and Kim & Fergusson (1993), who all identified petrol as a significant source of lead in house dust (up to 90% in urban samples), the lead in these southwestern Sydney samples should be principally derived from automobile exhausts. Copper and zinc levels, which were much less affected by the location or age of the building, were probably a reflection of the particular construction materials present at a given site.

Fractionation studies

Considering the high level of compositional heterogeneity in the house dust matrix, Hunt *et al.* (1992) recommended separation and pre-concentration of size fractions. Natusch *et al.* (1974) and Gulson *et al.* (1995) reinforced the importance of analysing the finer, more respirable particles (i.e. <100 µm sizes) of soil and dust as this fraction is likely to be highly concentrated in trace elements. Hence, for this study fractionation was performed to identify which particle size ranges dominated the bulk sample and/or contained the highest proportions of metal. Results of these analyses are presented in Tables 2 and 3, and Figs 3 and 4(i-iii).

Fractions 1 (>425 µm) and 8 (<53 µm) were found to be major contributors to the bulk masses of these ceiling dusts, both being more than double any of the remaining fractions. The mean total fines (i.e. total solids <106 µm, given by the sum of Fractions 6, 7 and 8; after consideration of White (1979)) was found to be approximately 56%.

Fig. 3 illustrates that each of the eleven sites followed a similar trend in the relative weight fractionation. Fraction 4 (150-180 µm) consistently contributed a low amount of particulate matter and possibly reflected the boundary between site-specific debris (Fractions 1-4) and aggregated aerosol matter that increased in amount as particle size became smaller (Fractions 4-8). The separate plots indicate that within-sample distribution was relatively reproducible, which was interesting given the otherwise heterogeneous nature of ceiling dust. Considering the spatial distribution of the sampling sites, this result would suggest that atmospheric inputs are an important source of solid materials in the roof cavity.

Despite repeatable within-site particle size distribution, no real pattern emerged amongst the individual metal levels, pre-

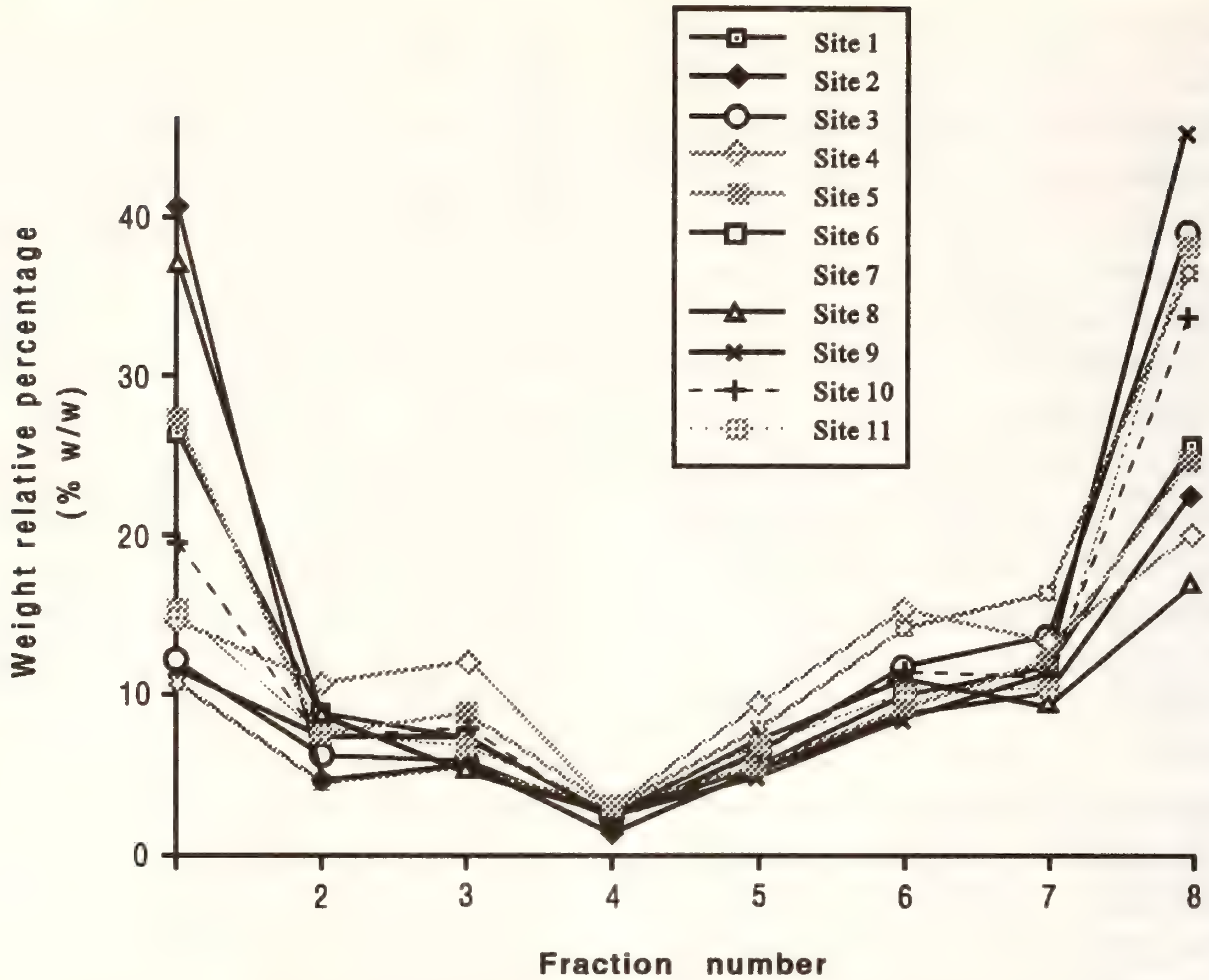

Fig. 3. Comparison of the weight relative percentages, following ceiling dust fractionation for the eleven study sites.

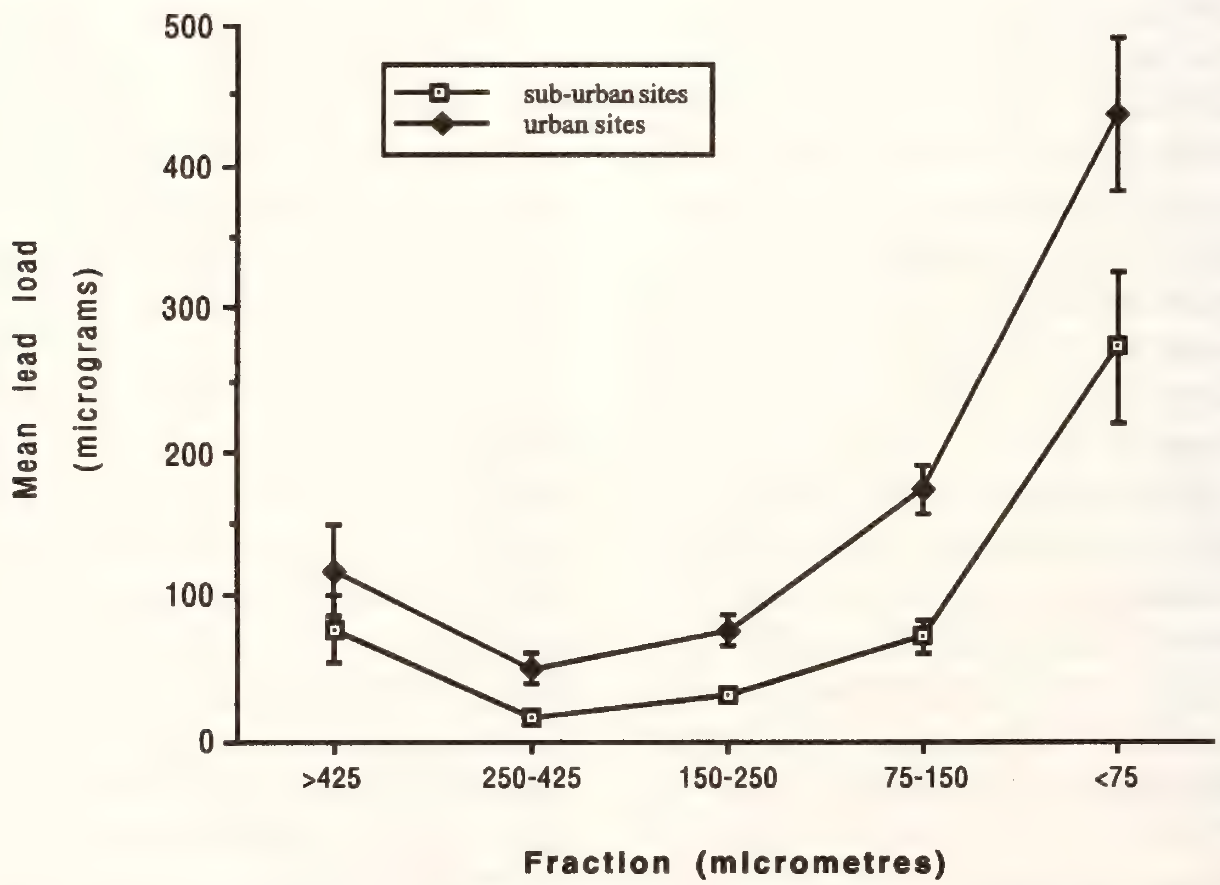

Fig. 4(i). Mean heavy metal loadings (per gram of unfractionated dust) for the urban and sub-urban Campbelltown sites - Lead. (Error bars are the standard errors).

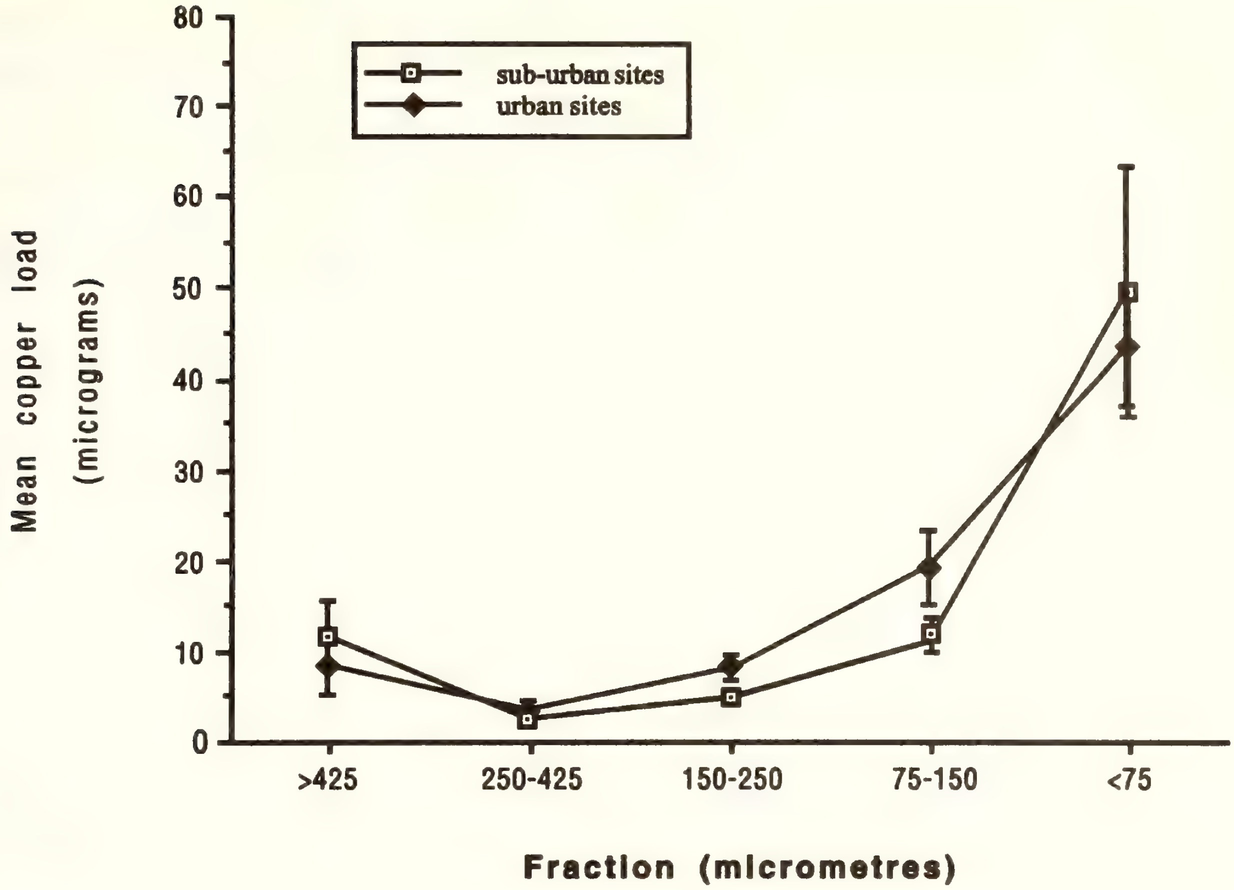

Fig. 4(ii). Mean heavy metal loadings (per gram of unfractionated dust) for the urban and sub-urban Campbelltown sites - Copper. (Error bars are the standard errors; copper data for sites 3 and 11 omitted).

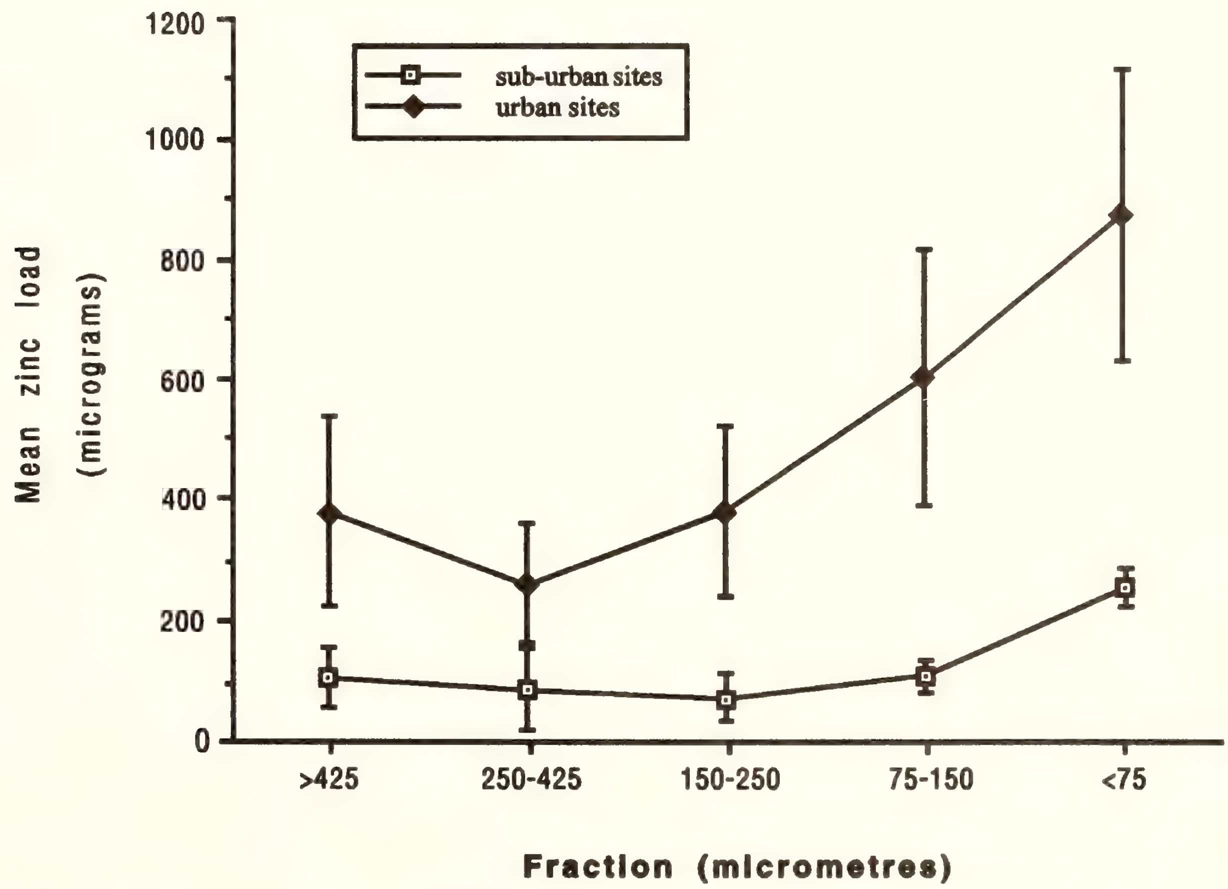

Fig. 4(iii). Mean heavy metal loadings (per gram of unfractionated dust) for the urban and sub-urban Campbelltown sites. 4(iii) Zinc (error bars are the standard errors).

sented as micrograms metal per gram of fraction (Table 3). In general terms, Fractions 7 and 8 are high in lead and copper, while zinc is usually high in the middle fractions (i.e. Fractions 3 to 5). One notable outlier occurred for Fraction 8 copper at site 11. Given that the house is approximately two years old and located in a quite sub-urban area, this anomaly may be due to some unexpected source at the site.

Trends are difficult to depict in this table since the fraction sizes are unequal and the values are metal concentrations per gram of fraction. Upon combining Fractions 3 and 4 (150-250 µm), Fractions 5 and 6 (75-150 µm) and Fractions 7 and 8 (<75 µm), and calculating the metal loads per gram of unfractionated dust, a clearer picture of metal distribution was generated. Fig. 4(i-iii) illustrates the mean load data for pooled sub-urban and urban sites. For copper, sites 3 and 11 were omitted.

Each metal displayed a similar pattern of decreasing load from the >425 µm to 250-425 µm fractions, followed thereafter by a steady rise as particle size decreased. Accompanying this rise was increased variability as measured by the standard errors. An exception was the zinc loading in the sub-urban sites, for which there was minimal difference amongst particles greater than 75 µm, and variability around the means became less.

Each pair of plots reflected the ANOVA results discussed earlier. For all fractions, the lead levels are clearly higher in urban samples and the two graphs are virtually identical. Minimal difference occurs in the case of copper and the plots are almost superimposed. For zinc, the urban means are much greater than the corresponding sub-urban values, but they also display much larger standard errors. Little change resulted if the data for sites 5 and 6 were omitted.

The fractionation results were consistent with the findings of Fergusson & Ryan (1984) and Gulson *et al.* (, 1995), who also observed increased metal concentrations with decreasing particle size. Given that the fines (i.e. the <106 µm particles) of these ceiling dusts are metal enriched and may account for more than half the sample mass, the atmosphere is thus a significant contributor of heavy metals to domestic environments in this region.

Human exposure to metals from dusts is heavily influenced by the particle population (Hunt *et al.,* 1992). Fine particulate matter (i.e. <100 µm) tends to be the most significant toxicologically, being highly respirable and showing greater exchangeability from larger surface area (Natusch *et al.*, 1974; White, 1979; Dreisbach & Robertson, 1987). Hence, ceiling dusts from urbanised areas could pose a health risk upon a major exposure.

CONCLUSIONS

High concentrations of lead, copper and zinc were detected in the ceiling dusts of eleven southwestern Sydney buildings, although considerable within-site heterogeneity was apparent, both in terms of metal levels and particle composition. Most of the observed concentrations (>85% of samples) exceeded the referenced soil quality guidelines. Lead, probably originating from automobile exhaust fumes, was significantly higher in older buildings (>15 years) located in heavily developed areas. This difference was expected for copper and zinc as well, however, large variabilities made these comparisons less distinct.

All eleven sites displayed remarkably similar particle size distribution, with the >425 µm and <53 µm fractions being major contributors to the bulk masses (each

greater than 20%). The patterns of metal loading were also similar, with metal levels rising as particulate size decreased beyond 250 µm. The fine particulate maker (< 106 µm) was noticeably metal enriched, especially in lead. Given that the fines may account for more than half the ceiling dust mass, the atmosphere is thus a significant contributor of particulate matter and associated heavy metals to domestic environments in this region.

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Identification of large reptilian teeth from Plio-Pleistocene deposits of Australia

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Abstract. Problems of identifying isolated reptilian teeth from Australian Plio-Pleistocene sites are discussed. There are problems of association because few crocodilian taxa are known from specimens with teeth *in situ.* The full range of variation in tooth form for these taxa is poorly understood. An attempt to assign certain tooth morphologies to known taxa has meant some arbitrary decisions but it is hoped that future material may clarify areas of uncertainty. Proposed identification of isolated reptilian teeth is facilitated by a dichotomous key, written descriptions and figured specimens.

INTRODUCTION

Numerous Plio-Pleistocene deposits from Australia have produced isolated teeth from crocodilians and the large varanid *Megalania.* The identification of these teeth has been difficult, inaccurate and confused (eg. Anderson 1930). Recent work on Australian Plio-Pleistocene crocodilians (Molnar 1981, 1982; Willis & Archer 1990; Willis & Molnar 1997) and on the large varanid *Megalania* (Hecht 1975) permits a more accurate identification of these teeth, at least to the level of genus.

Most large reptilian teeth from Plio-Pleistocene deposits in Australia represent three genera; the crocodilians *Pallimnarchus* and *Quinkana* and the varanid *Megalania.* The occurrence of *Crocodylus porosus* and *C. johnstoni* in Plio-Pleistocene deposits is rare (Molnar 1979, 1981; Willis & Archer 1990) but criteria are provided for the identification of these two taxa based on isolated teeth. While the intention here is to provide suites of characters that will permit the identification of isolated teeth, some criteria used here have been selected arbitrarily because of the unknown limits of individual variation within species. This problem is compounded by relatively small data sets for some species and such criteria may require modification as new material becomes available.

Abbreviations used for collections include AM F, Palaeontological collections of the Australian Museum; QM F, Palaeontological collections of the Queensland Museum.

LARGE REPTILIAN TEETH NOT CONSIDERED IN THE KEY

While crocodilians are usually considered to be homodont, there is some variation in the shape of teeth from the front of the dental arcade to the back. In extreme cases, this can be referred to as pseudoheterodonty. This identification process only deals with teeth from the anterior portion of the dental arcade. Teeth from the posterior of the crocodilian dental arcade (sometimes called pseudomolars) take on a similar, button-like morphology. Low, rounded pseudomolars with strong lateral compression may be attributed to *Quinkana*. Typical low, rounded, button-like pseudomolars appear to be similar in morphology for several taxa (e.g. species of *Crocodylus, Pallimnarchus* and *Baru)* and are thus excluded from this analysis.

THE RELATIVE ABUNDANCE OF LARGE REPTILIAN TEETH

Crocodilians and *Megalania* have different types of tooth replacement. Crocodilians have a thecodont dentition where teeth are regularly ejected and replaced throughout the life of the individual (Edmund 1962, 1969) . Most crocodilians have around seventy to eighty teeth in the mouth and each tooth is replaced an average of five times throughout the animals life. Thus, over three hundred and fifty teeth will be produced during the life of a single crocodilian (Edmund 1962, 1969). *Megalania* and other varanids have pleurodont dentition in which the teeth are not replaced as regularly as in crocodilians (Hecht 1975). Varanids in general and *Megalania* in particular have far fewer teeth than crocodilians, probably around fifty. Based on studies of tooth replacement rates in other species of *Varanus,* Auffenberg (1982) suggests that *Varanus komodoensis,* with 60 teeth, produced 200-250 teeth annually. This is a replacement rate of around 3.3 times per year and in two years it will produce well over 350 teeth. Thus, unless it had much lower rates of tooth replacement than modern varanids, an average individual of *Megalania* should have produced far more isolated teeth during a given period than a crocodilian such as *Pallimnarchus* or *Quinkana.*

However, teeth of varanids are much less common in Plio-Pleistocene deposits than those of crocodilians. Crocodilians typically inhabit lacustrine or fluviatile environments where fossilisation of isolated, ejected teeth is more likely. *Megalania is* assumed to have been exclusively terrestrial and its ejected teeth are unlikely to be fossilised in this environment. Perhaps this accounts for the disparity between the expected number of teeth produced and the numbers actually found and collected. In addition, there seem to have been several Pleistocene species of crocodilians (species of *Crocodylus, Pallimnarchus* and *Quinkana)* to only one species of *Megalania (M. prisca)*. However, since the numbers in the Queensland Museum collections are in the ratio of approximately 1 *Megalania* tooth to 80 crocodilian teeth, further explanation may be necessary. In any case it is clear that crocodilian teeth are much more likely to be found in Plio-Pleistocene deposits than those of *Megalania*.

ASSOCIATION OF TEETH AND BONES FOR LARGE REPTILIAN TAXA

Many maxillae and dentaries of *Megalania prisca* with the teeth still attached have been described and figured. De Vis (1900) figured and briefly described a maxilla with three teeth from Chinchilla, southeastern

Fig. 1. Teeth of *Megalania* cf. *M. prisca*. Top, labial; Centre, mesial and; Bottom, lingual views. A, QM F10966; B, QM F872; C, QM F29365. Scale bar 10 mm.

Fig. 2. Teeth of *Crocodylus johnstoni* (QM J45309). Top, distal (A, B) or mesial (C) and; Bottom, labial views. A, right maxillary 2; B. right maxillary 5; C, left maxillary 9. Serration-like plications may be seen on the carina in B (top). Scale bar 10 mm.

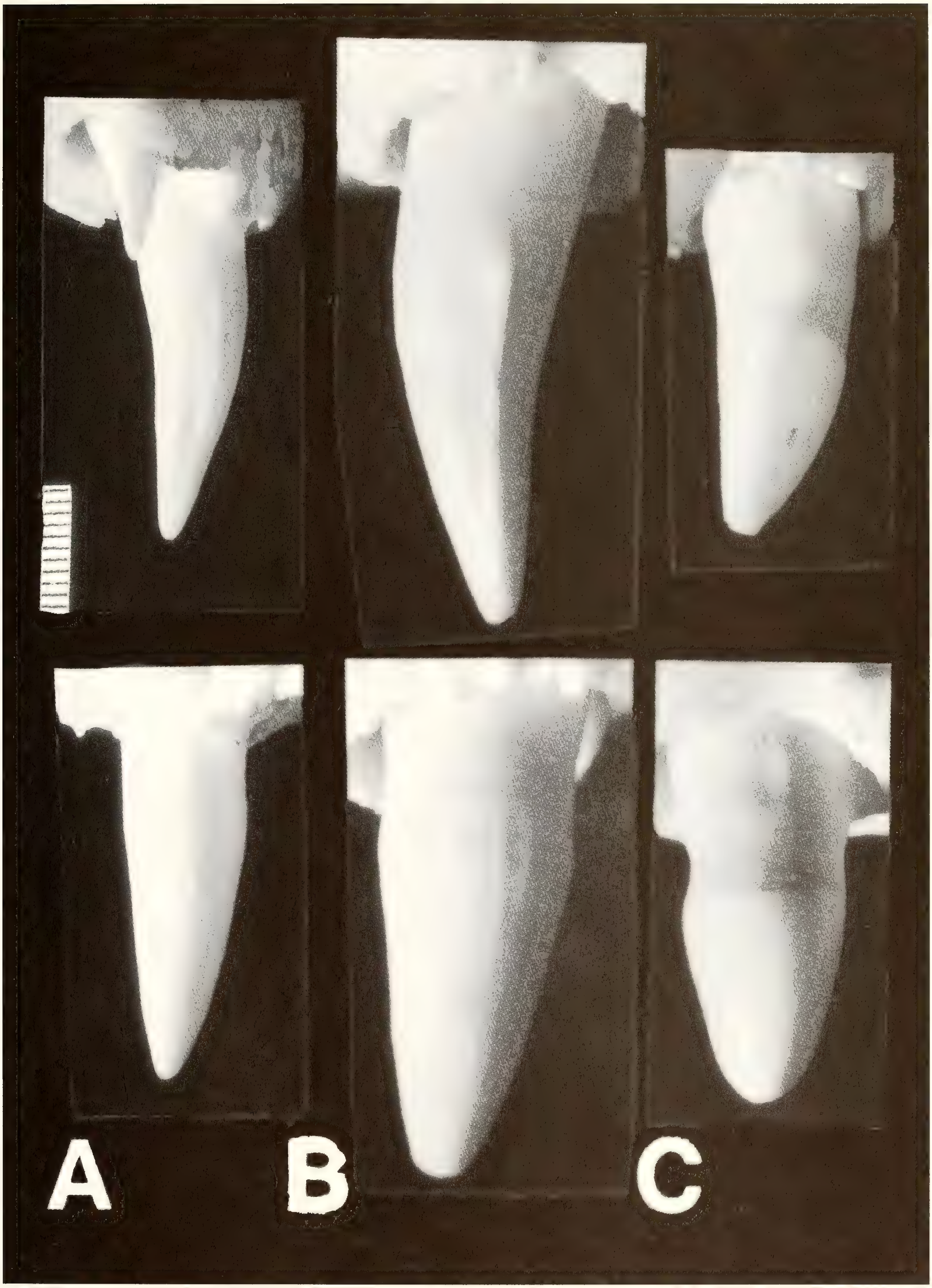


Fig 3. Teeth of *Crocodylus porosus* (QM J22550). Top, distal (A, B) or mesial (C) and Bottom, labial views. A, right premaxillary 3; B, left maxillary 5; C, left maxillary 9. Scale bar 10 mm.

Fig. 4. Teeth attributed to *Pallimnarchus* cf. *P. pollens*. Top, labial and; Bottom, mesial views. A, QM F29400; B, QM F29399; C, QM F3294 (note that this large tooth is curved both labio-lingually and mesio-distally, unlike smaller crocodilian teeth). Scale bars 10 mm: A and B to same scale.

Fig. 5. Teeth attributed to *Quinkana* cf. *Q. fortirostrum*. Top, labial or lingual and; Bottom, mesial views. A, QM F10968; B, QM F32153; C, QM F1167. Scale bar 10 mm.

Queensland in the collections of the Queensland Museum. He designated this specimen as *Varanus dirus,* which may be a junior synonym of *M. prisca* (Hecht 1975). Etheridge (1917) described a dentary of *Megalania prissa* from the Condamine River, southeastern Queensland, with a partial tooth attached (AM F2212). While undoubtedly *M. prisca,* this specimen represents a maxilla. Anderson (1930) identified five isolated teeth from Rosella Plains near Cairns, Queensland (AM F25227-8) as *M. prisca.* These teeth, according to the identification scheme presented here, belong to *Quinkana* cf. *Q. fortirostrum* (cf. Molnar 1981). Hecht (1975) described the most comprehensive collection of material referred to *M. prisca*, which included two partial maxillae, an almost complete mandible, several dentary fragments and a number of isolated teeth. One of the maxillae (AM F2212) is that described by Etheridge (1917) and the other (QM F14/870) may be that described by De Vis (1900) but, if this is the same specimen, two teeth had become detached by the time Hecht inspected it. More recently an almost complete maxilla (QM F12370), with several teeth attached, was collected near Waterford, southeastern Queensland. This material permits accurate and confident descriptions of the morphology of *Megalania* teeth.

Unfortunately the identification of crocodilian teeth from Plio-Pleistocene deposits in Australia is complicated by the paucity of specimens with the teeth still implanted in their sockets. This creates some ambiguity as to the correct identification of isolated crocodilian teeth. At present four crocodilian taxa have been described from Plio-Pleistocene deposits in Australia; *Pallimnarchus pollens* (De Vis 1886; Molnar 1981), *Quinkana fortirostrum* (Molnar 1982), *Crocodylus porosus* (Molnar 1979, 1981) and *C. johnstoni* (Willis & Archer 1990).

Several specimens of *P. pollens* (e.g. QM F11612) are known with teeth *in situ*: they are, however, recent replacement teeth. They are conical, circular to subcircular in cross-section, slightly curved lingually, with distinct carina. None of the carinae in the replacement teeth have serrations, but they do show a serration-like pattern in their enamel. The authors interpret this as a stage in the development of serrations in the growth of the tooth and thus, that the adult teeth were serrate. This, in turn, leads us to attribute to *Pallimnarchus* the isolated large conical teeth with distinct serrate carinae from the Plio-Pleistocene. We also note that very large teeth, here attributed to *Pallimnarchus,* are curved in both the mesio-distal (approximately parasaggital) and labio-lingual (approximately transverse) planes (Fig. 4C) unlike the smaller teeth of crocodilians in general that are curved only in the labio-lingual plane.

Two specimens of *Quinkana* (QM F7898 and an unnumbered specimen from Bluff Downs) are known that have teeth still in place. On QM F7898 the tooth, a recent replacement tooth, is small and broken. However, it clearly shows lateral compression and a distinct, serrate anterior carina. The unnumbered specimen from Bluff Downs was recently excavated by Brian Mackness and represents an anterior portion of the right maxilla with the fifth tooth *in situ.* The tooth is strongly compressed laterally, with distinct carinae that do not appear to be serrate. This is currently being described as a new species of *Quinkana* (Willis & Mackness 1996). The new Miocene species of *Quinkana, Q. timara* also has some teeth associated with the type material and the morphology of these teeth is similar to that of the Pleistocene species (Megirian 1994).

The dental morphology of both *C. porosus* and *C. johnstoni* is well known from extant populations and over 50 individuals of both species were examined for the present study.

In the anterior of the dental arcade the teeth are conical, curved lingually with slight carinae. The teeth of *C. porosus* are more robust than those of *C. johnstoni* and the teeth of *C. johnstoni* may have mild fluting toward the base.

It is assumed here that all isolated crocodilian teeth with serrate carinae or strong lateral compression recovered from Australian Plio-Pleistocene deposits relate to either *Pallimnarchus* or *Quinkana*. Thus, although consistent with the evidence, we acknowledge that the identification of serrate or compresssed teeth as *Pallimnarchus* or *Quinkana*, and nonserrate and conical teeth as *Crocodylus*, is somewhat arbitrary and these hypotheses may require modification once better material is recovered. A specimen of *C. porosus* in the Northern Territory Museum has been described as having serrate carinae (Megirian pers. comm.) and the several maxillary teeth of a *C. porosus* skull in the Queensland Museum (QM J22550) have a serrate-like pattern in the carinae (Fig. 3B, top), like those seen in the recent replacement teeth of *P. pollens*. Both these cases of serrate carinae in *Crocodylus* concern adult specimens. However, these are the only two cases of serrate carinae found in more than one hundred specimens of species of *Crocodylus* species examined for this study, and in both cases the serrations were poorly developed and not comparable to the true serrations seen in *Pallimnarchus* or *Quinkana*. This suggests that, although a few teeth of large specimens of *Crocodylus* may be weakly serrate, such occurrences are exceptional and, for practical purposes, may be ignored.

The designation of isolated teeth with distinct, usually serrate carinae to either *Pallimnarchus* or *Quinkana* is based on the degree of compression of the tooth. This character is useful because of the difference in degree of compression between, on one hand, the teeth and the empty alveoli on the three *Quinkana* specimens and empty alveoli of numerous *Pallimnarchus* specimens. Although no study has been done to demonstrate a correlation, or otherwise, between the tooth cross sectional shape to the shape of the alveoli, ten teeth and their respective alveoli have been measured from three specimens of *C. porosus* (Table 1). These data demonstrate a good correlation between the cross sectional shape of the tooth and the shape of the alveolus at the anterior of the dental arcade but a poorer correlation at the posterior (Fig 7). However, accepting that there is a strong correlation between cross sectional shape of the tooth and the shape of the alveolus at the anterior of the dental arcade, it can be inferred that there is a significant difference between the cross sectional shape of the teeth of *Pallimnarchus* and *Quinkana* (Table 2). In *Quinkana* the cross sectional (mesio-distal) length of the tooth is greater than 1.3 times the width of the tooth. In *Pallimnarchus,* this ratio is less than 1.3. The Bluff Downs *Quinkana* tooth has a ratio of 1.72. This criterion may need to be revised as more material becomes available.

The occurrence of *Crocodylus porosus* and *C. johnstoni* in Australian Plio-Pleistocene deposits is rare. The equally rare occurrence of nonserrate crocodilian teeth in these deposits is consistent with their correct identification as *Crocodylus* teeth.

CONFIDENCE OF IDENTIFICATIONS

Because of the problems of associating teeth with osteological material in *Pallimnarchus* and *Quinkana* and because there may be more than a single species in these two genera and *Megalania* (Hecht 1975; Molnar 1981, 1982; Willis & Molnar 1997) it is recommended that identification of isolated teeth as belonging to these taxa be restricted to the generic level with possible affinities to the currently recognised species (i.e.

Maxillary Tooth	Alveolus		Tooth	
Number	Mesio-distal	Width	Mesio-distal	Width
A - Specimen QM J47474				
1	13.8	13.0	9.8	7.4
2	15.1	15.1	10.4	10.5
3	16.7	13.3	12.5	10.0
4	18.0	20.0	14.3	13.8
5	23.1	23.1	18.7	18.3
11	17.8	12.1	12.3	9.6
12	14.6	9.8	9.7	7.3
13	13.5	8.6	8.4	6.1
B - Specimen QM J39232				
1	9.0	7.8	6.2	5.6
2	9.3	8.9	6.3	6.0
3	9.1	8.6	6.7	6.4
4	11.1	10.6	8.4	8.4
5	13.5	12.9	10.3	10.2
10	10.9	9.7	8.0	6.6
11	9.6	7.8	7.5	5.9
12	9.0	7.1	6.7	5.3
13	9.1	6.5	7.1	5.0
14	8.8	6.1	5.4	4.3
C - Specimen QM J13443				
1	9.2	8.2	7.0	6.3
2	10.7	10.4	7.1	6.9
3	11.5	11.0	8.5	8.1
4	17.0	16.7	11.5	11.4
5	18.9	18.0	14.5	14.2
10	12.2	12.2	9.4	7.2
11	13.7	11.7	8.8	8.0
12	11.2	9.6	7.3	6.3
13	10.6	8.7	6.1	5.3
14	9.4	5.9	5.4	4.2

Table 1. Alveolus and tooth measurements for three specimens of *C. porosus*. All measurements in millimetres.

alveolus	mesiodistal	sectional	ratio
Pallimarchus pollens	(Flinders University P25502)		
1	12.5	12.3	1.02
2	14.7	14.9	0.99
3	18.3	17.6	1.04
4	26.7	23.2	1.15
5	27.1	24.7	1.10
Quinkana fortirostrum	(Australian Museum F57844)		
1	11.2	8.0	1.40
2	12.5	9.0	1.39
3	13.1	8.9	1.47
4	14.2	9.3	1.53
5	11.6	8.4	1.38

Table 2. Cross sectional proportions of the first five maxilliary alveoli in *Pallimnarchus pollens* and *Qinkana fortirostrum.*

Pallimnarchus cf. *P. pollens, Quinkana* cf. *Q. fortirostrum, Megalania* cf. *M. prisca).* Assuming only two species of *Crocodylus,* identification of isolated teeth to either *Crocodylus porosus* or C. *johnstoni* can be made to the specific level based on the characters provided here.

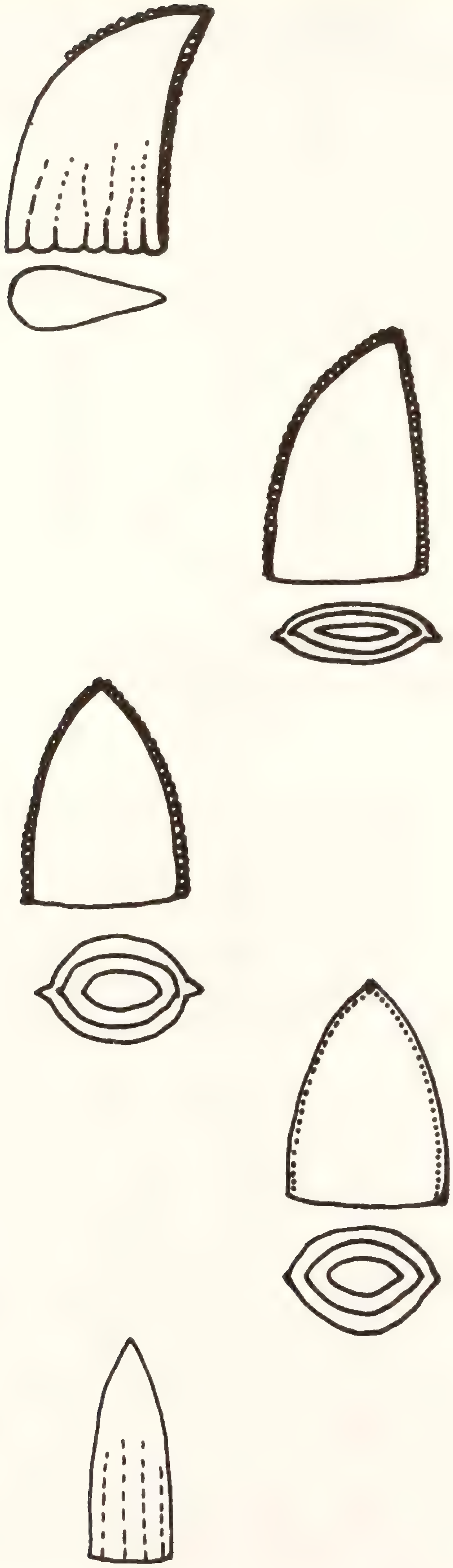
The authors would appreciate hearing from anyone finding large Plio-Pleistocene reptilian teeth that cannot be identified with this key.

KEY TO THE IDENTIFICATION OF ISOLATED LARGE REPTILIAN TEETH FROM AUSTRALIAN PLIO-PLEISTOCENE DEPOSITS

1. Crown of tooth strongly laterally compressed with tear-drop-shaped cross-section toward base; strong, narrow and irregular, sometimes bifurcating, fluting towards the base; serrate carinae; anterior carina absent or extending no more than one third the length of the tooth from the tip; crown strongly recurved and sickle-shaped in profile (posterior edge strongly concave); often showing occlusal wear; no indication of smaller replacement teeth internally; tooth is solid internally, without "cup" to accommodate a replacement tooth (Figs 1, 6) ....*Megalania*

   Crown of tooth may or may not be laterally compressed; lenticular cross section toward base; basal fluting (if present) weak, relatively broad and regular, not bifurcating; carinae either serrate or nonserrate; anterior carina usually extends to the base of the crown; tooth never strongly recurved, i.e. posterior edge never strongly concave; rarely showing any occlusal wear; one or more replacement teeth usually preserved internally or, if absent, conical, cup-like cavity present in base of tooth ....crocodilian, 2

2. Carinae usually nonserrate, poorly defined against the body of the tooth;



Megalania prisca
* serrations on upper third of anterior carina
* posterior margin concave
* strong, irregular fluting at base
* tear-shapes cross section
* no internal structures

Quinkana c.f. *Q. fortirostrum*
* serrations to base of anterior carina
* carina distinct from body of tooth
* compressed, lenticular cross section
* internal structure; either an empty 'cup' or with replacement teeth
* no fluting

Pallimnarchus c.f. *P. pollens*
* serrate carinae
* robust, conical form
* distinct carinae
* ovoid cross section
* no fluting
* internal 'cups'

Crocodylus porosus
* non-serrate carinae
* robust, conical form
* carinae poorly developed
* no fluting
* ovoid section
* internal 'cups'

Crocodylus johnstoni
* similar to *C. porosus* but more slender
* no serrations
* may have weak, regular fluting toward base
* ovoid section
* carinae poorly developed
* internal 'cups'

Fig. 6. Schematic drawings of the five different types of teeth identified in the key showing characteristic features. Teeth shown in profile and basal views (not to scale).

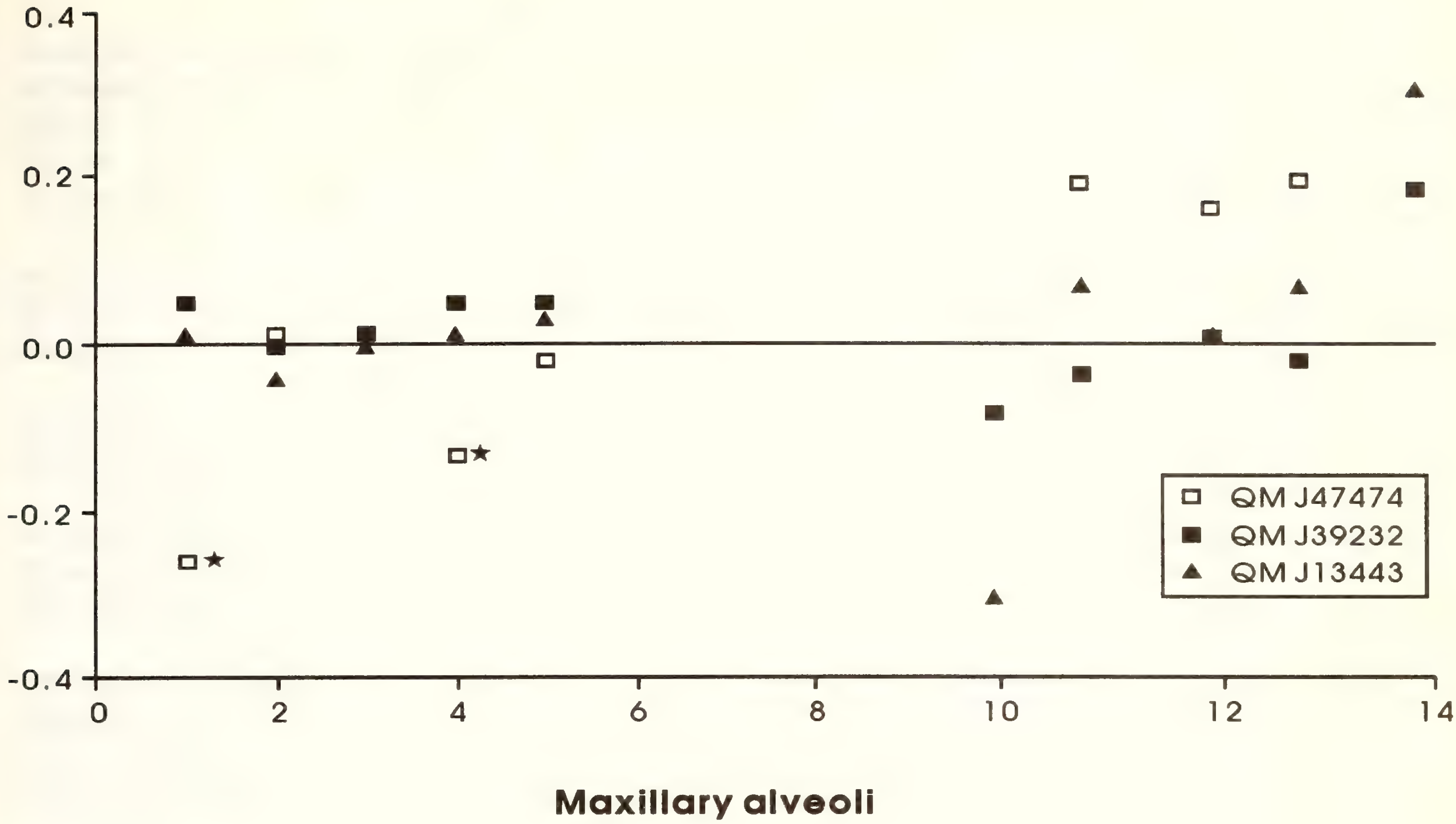


Fig. 7. Correlation between tooth shape and alveolus shape. Data from Table 1 has been analysed by the following formula:

$$\frac{\text{Alveolus mesio-distal}}{\text{Alveolus width}} - \frac{\text{Tooth mesio-distal}}{\text{Tooth width}}$$

Values close to 0 indicate a good correlation between alveolus and tooth cross sectional shape. Values marked with an asterix (*) are where the tooth is damaged giving a poor representation of true tooth cross sectional shape.

tooth not strongly laterally compressed ....*Crocodylus,* 3

Carinae may be serrate and well defined against the body of the tooth; tooth may be strongly compressed 4

3. Tooth long and gracile; sometimes with mild to moderate length-wise fluting (Figs 2, 6) ....*C. johnstoni*

Tooth moderately long, robust; lengthwise fluting rare and, at most, only mildly developed (Figs 3, 6) ....*C. porosus*

4. Crown of tooth conical, cross-sectional width not much smaller than cross-sectional length (medio-distal length/width < 1.3); profile more or less symmetric (Figs 4, 6) ....*Pallimnarchus*

Tooth blade like, cross sectional width much smaller than cross-sectional length (medio-distal length/width > 1.3); profile strongly asymmetric (Figs. 5, 6) ....*Quinkana*

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Destruction of Ozone-depleting Substances in a Thermal Plasma

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Abstract. The destruction of ozone-depleting substances (ODSs) using the PLASCON™ thermal plasma technology is discussed. An introduction to thermal plasmas is presented, and their application to waste destruction is reviewed. The PLASCON process is then described, and some examples of the experimental and theoretical research that has contributed to its successful commercialisation are presented. An important observation is that significant quantities of CFC-13 (CF_3Cl), itself an ODS, are formed during the destruction of an input ODS. A numerical model of the fluid dynamic and chemical kinetic processes occurring in PLASCON has been used to elucidate the mechanism for the CFC-13 formation. The predictions of the model are in fair agreement with measurements of exhaust gas composition, and with laser-scattering measurements of temperatures in the reaction tube.

INTRODUCTION

It is well established that the recent depletion of stratospheric ozone is a result of the release of man-made chemicals, such as chlorofluorocarbons (CFCs) and halons. This was recognised in the award of the 1995 Nobel Prize for Chemistry to Paul Crutzen, Mario Molino and F. Sherwood Rowland for their work on the mechanisms of the formation and decomposition of ozone in the stratosphere.

The 1992 Copenhagen amendment to the 1987 Montreal Protocol (United Nations Environment Program 1992) specified that the use of halons and CFCs was to be phased out by 1994 and 1996 respectively. Further, it required that if stockpiles of these substances were destroyed, the destruction was to be at a level of greater than 99.99%. Various means of reaching this level have been proposed. These include conventional incineration, reaction with sodium under ultraviolet light, catalytic techniques, and hydrolysis using supercritical water (Chemical Product Council 1989; Cross & Hadfield 1992, Sekiguchi, Honda & Kanzawa 1993).

The most promising and best-developed approach to the destruction of ozone-depleting substances (ODSs) is probably the use of thermal plasmas to heat the ODSs to very high temperatures. Such methods are being investigated in Australia (Deam *et al.* 1995; McAllister 1995), France (Pateyron *et al.* 1995a,b), Japan (Sekiguchi, Honda & Kanzawa 1993; Sekiguchi, Matsudera & Kanzawa 1995; Takeuchi *et al.* 1995), and the USA (Han, Heberlein & Pfender 1993). In December 1996, a plant to destroy Australia's stockpile of halons, based on the PLASCON thermal plasma technology

jointly developed by CSIRO and SRL Plasma, a subsidiary of Siddons Ramset Limited, was opened in Melbourne by the Commonwealth Department of Administrative Services Centre for Environmental Management (DASCEM).

In this paper, after outlining the principles of thermal plasma technology and its applications, particularly to the treatment of waste, I will introduce the PLASCON process. I will then describe some of the scientific research that was involved in the development of the process to its current status.

THERMAL PLASMAS

A plasma is a mixture of electrons, ions and neutral species that is locally electrically neutral. The presence of free electric charges means that a plasma, unlike a non-ionised gas, has a high electrical conductivity. Plasmas are typically produced by electric discharges, and can be divided into two broad categories, thermal or equilibrium plasmas, and cold or non-equilibrium plasmas. Cold plasmas are produced in glow discharges, low-pressure radio-frequency discharges and corona discharges, and are used, for example, in the etching of semiconductors and in fluorescent lights. They are characterised by their relatively low energy density, and by the large difference between the electron temperature and the heavy particle temperature, which is typically close to room temperature.

In contrast, the temperatures of the heavy particles and the electrons in thermal plasmas are similar, typically of the order of 10 000 to 20 000 K. The much higher heavy particle temperature means that the energy density is much larger than in cold plasmas. Thermal plasmas can be

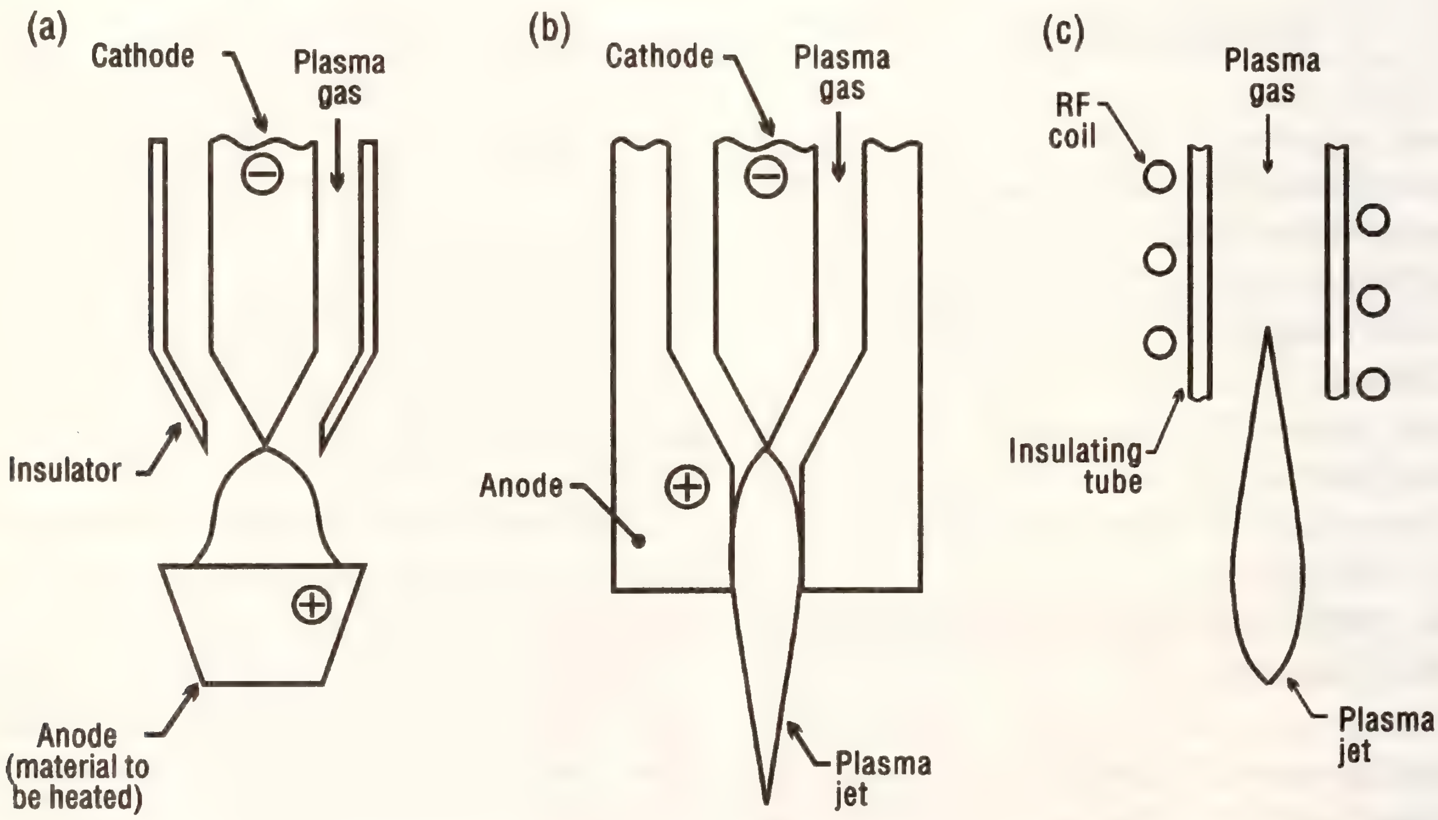


Fig. 1. Methods of generation of thermal plasmas. (a) DC electric arc, and example of the transferred arc; (b) DC plasma torch, an example of a non-transferred arc; (c) radio-frequency inductively-coupled plasma torch.

generated in a number of ways, such as by DC or AC electric arcs between electrodes separated by anything from a few millimetres to a metre; by DC plasma torches, in which an arc is struck between a cathode and a cylindrical anode, producing a jet of plasma from the aperture of the anode; and by radio-frequency inductively coupled plasma torches, in which the plasma is heated using the electromagnetic field of an induction coil. Fig. 1 illustrates these generation methods, and also shows the difference between transferred arcs, in which one electrode is the object to be heated, and non-transferred arcs, in which the arc remains within the plasma torch and is not transferred externally. Further details of these generation methods are given, for example, by Boulos (1991) and Fauchais (1992).

Thermal plasma technology has found a wide range of industrial applications. Such well-established processes as electric arc welding and electric arc furnaces are plasma technologies. More recent applications include plasma welding and plasma cutting of metals, deposition of heat- and wear-resistant coatings by plasma spraying, metallurgical applications such as melting and remelting of metals and extraction of metals from ores, and the synthesis, spheroidisation and densification of powders (Pfender 1988; MacRae 1989; Boulos 1991; Fauchais 1992).

WASTE DESTRUCTION USING THERMAL PLASMAS

Recently, much attention has been focussed on the use of thermal plasmas to destroy hazardous chemicals. The conventional method for such destruction is high-temperature incineration; however the use of plasmas has advantages in many applications. These include the properties that the generation of heat is independent of the chemistry, being supplied electrically rather than through combustion, and that higher temperatures can be achieved, meaning that a given level of destruction can be attained more rapidly. Further, the size of a plasma waste destruction plant can be sufficiently small to allow it to be built on the site of the waste repository, or even to be mobile, so the need for transportation of waste is circumvented. In some countries, including Australia, the construction of high-temperature incinerators is politically unacceptable, so that there is a definite need for alternatives.

A number of different approaches have been taken to the design of plasma waste treatment systems, mainly determined by the type of waste to be treated or destroyed. Solid wastes are often treated using a transferred arc system, in which an electric arc is established between an electrode and the waste to be treated, which, when molten, conducts electrically. Retech, a division of Lockheed Environmental Systems and Technologies (LESAT), USA has developed the Plasma Arc Centrifugal Treatment (PACT) system, in which the waste is contained in a spinning cupola (Eschenbach & Haun 1995). Production size systems are used by MGC Plasma, Switzerland in their PLASMARC and PLASMOX process for treatment of metallurgical, low-level radioactive, and military wastes (Hoffelner & Fünfschilling 1995; Hoffelner *et al.* 1995). Other such systems will be used by LESAT to remediate a radioactively contaminated pit in Idaho, USA, and smaller systems are being used in treatability studies in France, Switzerland and the USA.

LTEE, the research and development laboratory of Hydro-Québec in Canada, has developed an electric arc technology in which the radiation from a transferred arc melts

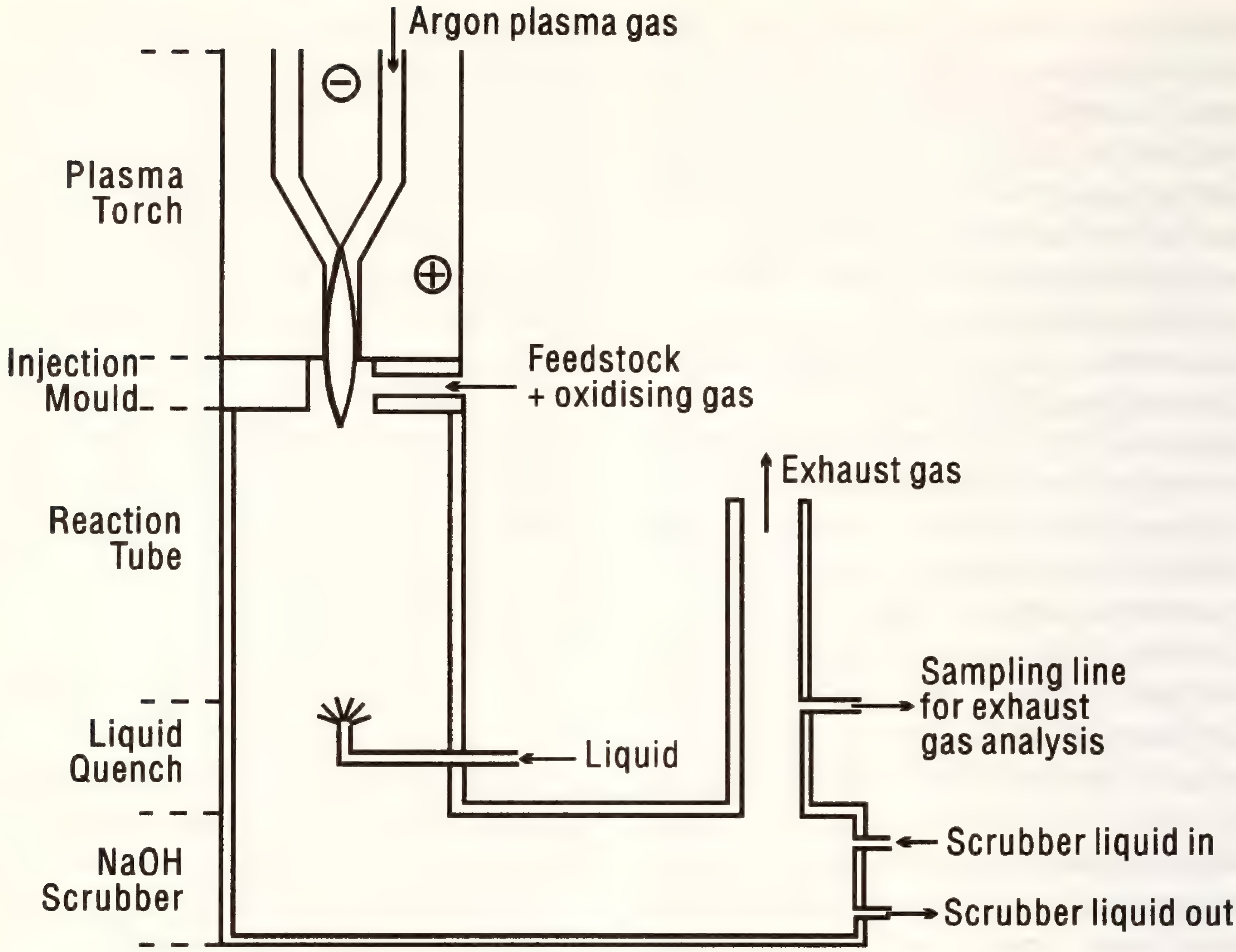


Fig. 2. Schematic of the PLASCON process

the metallic dust recovered from baghouses on electric arc furnaces. The molten metal is then collected for recycling. A similar arc technology is used to vitrify incinerator fly ash (Laflamme *et al.* 1995).

Arc furnaces are being developed for treatment of radioactive and mixed wastes in soils at the Plasma Fusion Center, Massachusetts Institute of Technology, USA. Other transferred arc systems are being investigated by Plasma Energy Corporation and Phoenix Solutions Co. in the USA (Paul 1995).

A different approach to the treatment of solid waste involves the use of non-transferred DC plasma torches, heat being transferred to the waste indirectly through the plasma gas. Such an approach has been taken by Aerospatiale of France. Several processes have been developed that use plasma torches to treat solid waste streams; the INERTAM process is a mobile asbestos waste vitrification unit, the EUROPLASMA process treats fly ash from municipal waste incineration, and the INCIDIS process is designed for highly-chlorinated toxic waste (Valy & Guillet 1995). Another plasma-torch-based system for solid waste destruction has been developed by Electricité de France (Guenard & Bourdil 1992). At Georgia Institute of Technology, plasma-torch-based systems are being developed for a range of applications, including *in situ* vitrification of contaminated soils (Paul 1995).

Other waste destruction technologies are based on radio-frequency inductively coupled discharges; for example, the PERC™ (Plasma Energy Recycle and Conversion) treatment process developed by Plasma Technology, Inc., USA is designed to destroy a range of gaseous, liquid and solid waste streams (Blutke, Vavruska & Serino 1995), and Tekna Plasma Systems Inc. of Canada are developing similar technology (Boulos 1995). Nippon Steel Corporation use a steam plasma generated by a radio-frequency discharge to destroy CFCs (Takeuchi *et al.* 1995).

Plasma torches are ideally suited to the destruction of gaseous and liquid waste streams, which can be injected into the high temperature region of the plasma jet emanating from the torch. An early example of this approach was a system conceived at the Royal Military College of Canada that was tested on polychlorinated biphenyl (PCB) solutions (Barton, 1984); this system was further developed by Westinghouse Environment Services (Heberlein *et al.* 1989). Further examples of plasma-torch-based systems are the PLASCON technology, described in the next section, the process of Sekiguchi *et al.* (1995) from the Tokyo Institute of Technology, in which a plasma jet incident on a fluidised CaO bed is used to destroy CH_3Cl, a similar system tested by Pateyron *et al.* (1995b) from the University of Limoges, France on CF_4 destruction, and a process developed by KAI Plasmapyrolyse of Germany that has been tested on chlorinated hydrocarbons (Lachmann *et al.* 1993).

THE PLASMACON TECHNOLOGY

The PLASCON™ (PLASma CONversion) waste destruction technology was jointly developed by CSIRO and SRL Plasma. One full-scale 150 kW system, and a smaller 50 kW system are operated at CSIRO Division of Manufacturing Technology in Melbourne, and a 50 kW system is installed at CSIRO Telecommunications and Industrial Physics in Sydney. The first commercial installation was commissioned in 1992 at Nufarm Ltd's herbicide manufacturing facility in Melbourne, where a second plant was completed in 1995. Together these plants destroy the liquid waste stream of Nufarm's manufacture of 2,4-D (2,4 dichlorophenoxy acetic acid), a selective agricultural herbicide. In December 1996, a 150 kW plant owned by SRL Plasma Ltd and designed to destroy Australia's stockpile of halons was officially opened in Melbourne. The plant is being operated by SRL Plasma under contract to the Commonwealth Department of Administrative Services. The destruction of other wastes, including PCB transformer oil (Vit, Deam & Mundy 1993; Western, Vit & McAllister 1995), has also been experimentally demonstrated.

The PLASCON process is shown schematically in Fig. 2. The plasma is produced by a DC plasma torch, with argon as the plasma gas. The liquid or gaseous feedstock, together with an oxidising gas, for example, oxygen, is injected through an injection manifold into the argon plasma jet, whose temperature exceeds 10 000 K at this point. The oxidising gas prevents the formation of carbon soot, which can be detrimental to the effectiveness of destruction, and which can cause clogging in other parts of the process. The resulting mixture of hot gases passes through a reaction tube, and is then rapidly cooled by a liquid spray quench to prevent undesirable recombination reactions. The cooled gases are next passed through a scrubber to remove acid gases and halogens, before being released to the atmosphere. Both the spray quench and the scrubber liquid are aqueous solutions of

sodium hydroxide. New solution is continually added, and spent solution is drained, in order to keep the pH of the scrubber liquid in the basic range.

A 150 kW PLASCON plant can process between 1 and 5 t of feedstock per day, depending on the type of waste being treated. The capital cost is low relative to comparable destruction technologies, a little over $1 000 000, and the operating costs for concentrated waste are typically in the range $2000 to $2800/t. PLASCON is designed for on-site operation, eliminating the need to transport hazardous wastes to a large central facility.

DESTRUCTION OF OZONE-DEPLETING SUBSTANCE USING PLASCON

Laboratory tests of the destruction of a range of ODSs have been performed in the 50 kW devices in both Sydney and Melbourne. These were CFC-11 ($CFCl_3$), CFC-12 (CF_2Cl_2), HCFC-22 (CHF_2Cl), Halon 1211 or BCF (CF_2ClBr) and Halon 1301 or BTM (CF_3Br). The two halons were widely used as fire extinguishers, while the CFCs were used as refrigerants, in air-conditioning, for foam production, as aerosol propellants, etc. In parallel with the laboratory tests,a programme of chemical and fluid dynamic modelling of ODS destruction was carried out. The experimental and the modelling programmes are discussed in the following two subsections.

Laboratory tests

The experimental programme had two main aims; to establish the parameters for which the input rate of a given ODS was maximised while maintaining the destruction rate of 99.99% specified by the Montreal Convention, and to determine materials and configurations that gave adequate component lifetimes. Here I will concentrate on the first of these aims, since the results of the second are largely commercial-in-confidence.

Experiments were performed in the 50 kW PLASCON devices at CSIRO in Sydney and Melbourne. A gas chromatograph fitted either with a mass spectrometer, or with a thermal conductivity detector and an electron capture detector, was used to analyse samples of the exhaust gases. In the latter case, the thermal conductivity detector was used to detect the bulk gases (present in concentrations greater than around 1 part in 10 000), while the electron capture detector was particularly sensitive to molecules containing chlorine and bromine atoms, and was thus ideally suited to measuring small concentrations of many ODSs. In the course of the experiments, parameters such as the argon plasma gas flow rate, ODS input rate, input rate of the co-injected oxidising gas, and the electrical power were varied. Typical results are given in Table 1 for three different ODSs: CFC-11, CFC-12 and CFC-13. Results for the concentrations of the ODSs in the exhaust gas, and in one case for other gases, are presented.

In all cases, substantial conversion of the input ODS to a different ODS, CFC-13 is observed. CFC-11, CFC-12 and CFC-13 all have stratospheric ozone depletion potentials of 1.0, and the rating of HCFC-22 is 0.055. (United Nations Environment Program 1992). Hence, if only the concentration in the exhaust gas of the input ODS were measured, then the ozone depletion potential of the exhaust gas would be assumed to be significantly smaller than is actually the case. This effect, as noted by Deam *et al.* (1995), indicates that performance of an ODS destruction technology should be expressed in terms of the total

INPUT CFC	Power (kW)	Input flow (1 min^{-1})			Concentrations in exhaust gas					
		Ar	CFC	O_2	$CFCl_3$	CF_2Cl_2	CF_3Cl	CHF_2Cl	CF_4	CO_2
$CFCl_3$	30	45	31	34	60 ppm	1 ppm	34 ppm	*	†	†
CF_2Cl_2	22	45	27	30	*	0.5 ppm	62 ppm	*	†	†
CF_2Cl_2	30	42	40	45	*	*	50 ppm	*	4-5%	1%
CHF_2Cl	15	45	45	45	*	1 ppm	36 ppm	12 ppm	†	†

* Below detectable levels
† Not measured

Table 1. Measured concentrations of species in exhaust gas.

ODS concentration in the exhaust gas, rather in terms of destruction of the input ODS only. It is not apparent that other groups working on ODS destruction have taken note of this; for example Sekiguchi *et al.* (1993) gave only the qualitative result that no CFC-12 had been detected in their plasma destruction of CFC-12, and did not indicate whether they had tested for CFC-13 or other ODSs.

The other gases emitted, argon (whose concentration is unchanged throughout the process), carbon dioxide, oxygen and carbon tetrafluoride (CFC-14), are all non-toxic and have no ozone-depleting potential. Carbon dioxide is, of course, a greenhouse gas, but it is emitted in miniscule quantities compared to other sources; further, CO_2 is a much weaker greenhouse gas than the input ODSs.Carbon tetrafluoride, however, is a stronger greenhouse gas than the ODSs destroyed, so it is desirable that its emission be avoided. It is known (e.g. Takeuchi *et al.* 1993; Pateyron *et al.* 1995a) that the introduction of steam or hydrogen into the plasma greatly decreases the formation of CF_4, thereby solving this problem.

Other gases that may be produced, such as HF, HCl, HBr, F_2, $C1_2$, Br_2, COF_2 are all dissolved in the caustic soda (NaOH) scrubber, forming aqueous solutions of NaF, NaCl, NaBr and Na_2CO_3. In summary, the output products from the destruction of halons and CFCs are argon, CO_2, CF_4, trace quantities of ODSs, and the aqueous solution of sodium salts (with NaBr present only in the case of halons). The ODS present in the greatest quantity is usually CFC-13. The products can be safely discharged into the environment, the gases to the atmosphere and the aqueous solution to sea water.

It is found that as the input rate of the ODS increases for a given electrical power, the total ODS concentration in the exhaust gas increases rapidly. While for the parameters listed in Table 1, the ODS concentration remains below the 1 part in 10 000 required, if the input rate is increased significantly or the electrical power decreased, this is no longer the case.

Modelling of ODS Destruction

A numerical model of the electromagnetic, fluid dynamic and chemical kinetic proc-

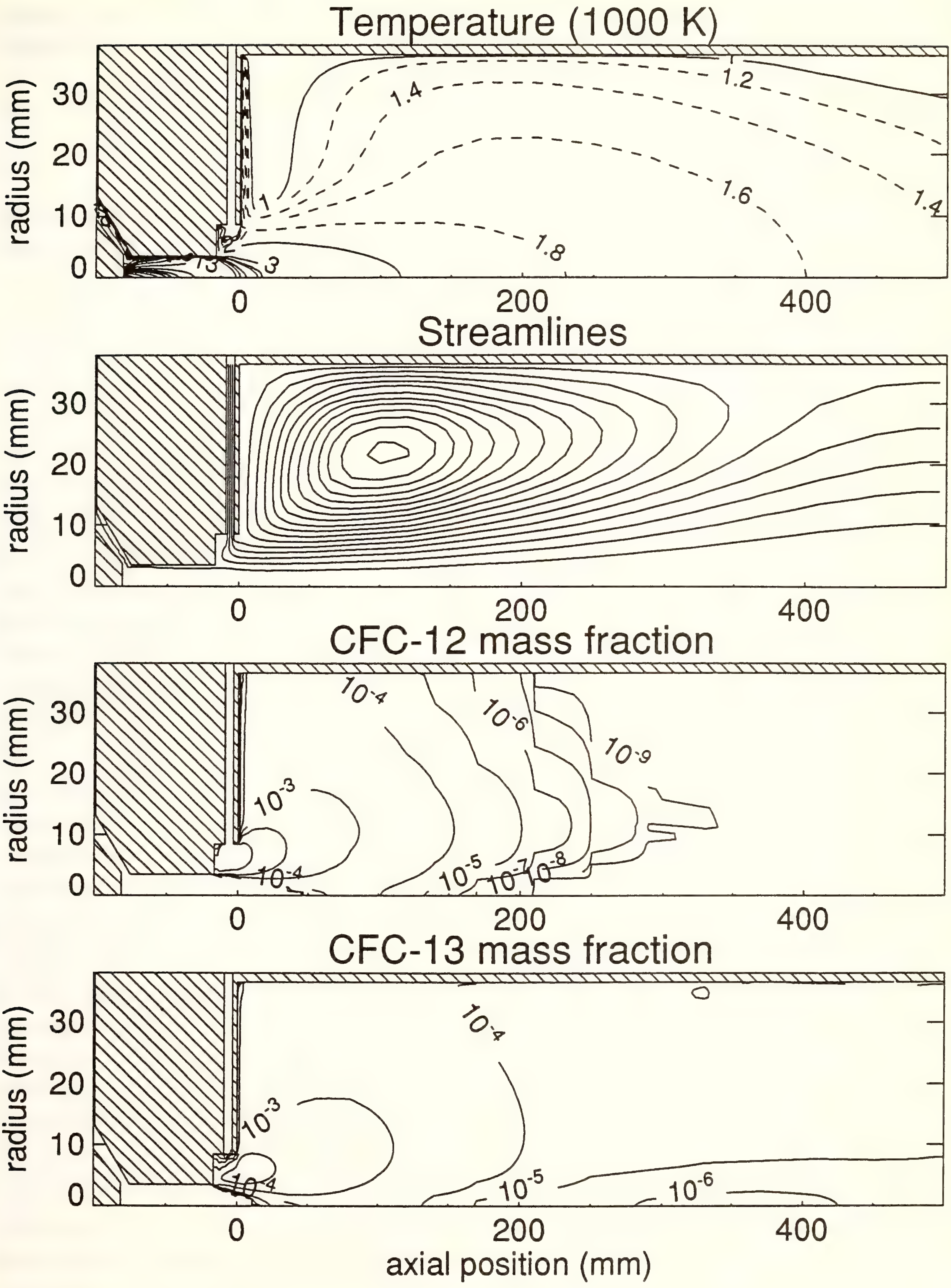
esses occuring in the PLASCON plasma torch, injection manifold and reaction tube has been developed. The model is based on the model of a plasma torch discharging into the atmosphere that has been described by Scott *et al.* (1989) and Murphy & Kovitya (1993).

Cylindrical symmetry is assumed, so radial and axial variations of parameters are taken into account, but not azimuthal variations. The coupled partial differential equations describing mass continuity, conservation of momentum in the axial, radial and azimuthal directions, conservation of energy, conservation of mass of the individual chemical species, electric charge continuity, and the two equations of the K-ε turbulence model are solved numerically using the control-volume method of Patankar (1980), which is a finite-difference scheme. The equation of state was included in the model implicitly by calculating the thermodynamic properties of the gas mixture for any given temperature and composition using a computer code developed by NASA (Gordon & McBride 1971). Equilibrium compositions and transport coefficients (Svehla & McBride 1973; Kovitya 1984) were also calculated using this code.

The numerical model consists of two stages which are run consecutively. The first solves the fluid dynamic and electromagnetic equations to give temperatures, flow fields and electric current densities. It is assumed in this stage that the chemical composition corresponds to that determined by equilibrium calculations, except that a one-step chemical kinetic scheme is used to model the initial dissociation of the injected ODS. In the second stage, a full chemical kinetic scheme is solved to give concentration fields of all chemical species. The model is not fully self-consistent, since the temperature and flow fields are not recalculated to take into account the differences in enthalpies and material properties that occur when the full kinetic scheme is used.

The model has keen used to simulate the destruction of CFC-12, injected together with oxygen, for conditions typical of the 50 kW PLASCON device. A chemical kinetic scheme involving 23 chemical species and 42 reactions, developed by McAllister (1995, 1996), was used. Representative results are given in Fig. 3 for temperature and flow fields, and for concentration fields of CFC-12 and CFC-13. It can be seen that inside the plasma torch, the temperature of the argon plasma gas is predicted to reach over 27 000 K. At the entrance to the injection manifold, the temperature on axis is just over 13 000 K, the decrease being due mainly to conduction to the body of the torch. The influx of cold gas (CFC-12 and O_2) into the injection manifold region leads to a rapid cooling, with much of the enthalpy of the argon being used to break the molecular bonds of the injected gas, so that the temperature drops to 3000 K on axis 25 mm downstream of the injection manifold. The temperature is between 1000 K and 2000 K in most of the reaction tube, falling to close

Fig. 3 (opposite). Isotherm, streamlines and isopleths of mass fraction of CFC-12 and CFC-13 for 15.0 kW arc power, 42 L min^{-1} argon flow, and injection of a mixture of 40 L min^{-1} CFC-12 and 40 L min^{-1} oxygen, calculated using the numerical model. The plasma torch extend from axial position z = -100 to -16.4 mm, the injection manifold from z = -16.4 to 0 mm, and the reaction tube from z = 0 to 500 mm. Note that while the orientation of the plots is horizontal, the components are in fact vertically oriented, as shown in Fig. 2. Isotherms are labelled in units of 1000 K; the solid lines correspond to 1000 K, 2000 K, 3000 K, 5000 K, 7000 K, ... 27 000 K.


Temperature (1000 K)
radius (mm)
1.2
1.4
1.6
1.4
1.8
1
2
3
3
0
10
20
30
0
200
400
Streamlines
radius (mm)
0
10
20
30
0
200
400
CFC-12 mass fraction
radius (mm)
10^{-4}
10^{-6}
10^{-9}
10^{-3}
10^{-4}
10^{-5}
10^{-7}
10^{-8}
0
10
20
30
0
200
400
CFC-13 mass fraction
radius (mm)
10^{-4}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
10
20
30
0
200
400
axial position (mm)

to 300 K at the walls, which are water-cooled.

The streamlines show that a large recirculation region exists in the reaction tube at radii greater than that of the injection manifold aperture, extending downstream about 350 mm from the injection manifold exit. The presence of a recirculation region ensures that the direction of flow in the reaction tube near the end of the injection manifold is towards the high-temperature region near the axis; similarly the flow near the wall in the first half of the reaction tube is directed backwards towards the injection manifold. This ensures that very little injected gas can escape from the reaction tube after travelling only through the cool regions near the end of the injection manifold and the reaction tube wall. The presence of the recirculation region is thus an advantage in the destruction of the injected gas.

The mass fraction of CFC-12 decreases to 10^{-8} within 300 mm of the injection manifold aperture. The mass fraction decreases because of two effects; destruction of the CFC-12, and dilution by the argon plasma gas. For the flow rates of argon and injected gas considered here, the mass fraction of CFC-12 would be 0.62 if full mixing but no destruction occurred, so the dilution effect is relatively minor.

Rapid production of CFC-13 is calculated to occur in a small region within, and up to about 10 mm downstream of, the injection manifold. This occurs mainly through a reaction scheme (Deam *et al.* 1995) that begins with the dissociation reactions:

$$CF_2Cl_2 + M \longrightarrow CF_2Cl + Cl + M \quad (1)$$

and

$$CF_2Cl + M \longrightarrow CF_2 + Cl + M \quad (2)$$

(M denotes any species). The dissociation of oxygen molecules yields oxygen atoms, which react to give chlorine and fluorine atoms:

$$CF_2Cl + O \longrightarrow CF_2O + Cl, \quad (3)$$

$$CF_2 + O \longrightarrow CO + 2F. \quad (4)$$

These in turn recombine with CF_2 to yield CFC-13 through a series of three-body reactions:

$$CF_2 + F + M \longrightarrow CF_3 + M, \quad (5)$$

$$CF_3 + Cl + M \longrightarrow CF_3Cl + M. \quad (6)$$

The rate of decomposition of CFC-13 is less than that of CFC-12. Nevertheless, it is slowly broken down in the reaction tube, reaching a mass fraction of less than 10^{-4} at the end of the tube for the conditions considered. As noted above, the model has indicated that the CFC-13 is formed in a small region within and near the injection manifold. It is hence unlikely that changes to the geometry of the reaction tube, for example, will greatly affect the amount of CFC-13 formed; numerical simulations using a different reaction tube diameter have supported this presumption. The most effective way to decrease the CFC-13 level at the exit to the reaction tube is to increase the temperature in the tube, thereby increasing the rate of breakdown of the CFC-13 that is formed. This can be done by increasing the arc power or decreasing the CFC-12 input flow. If, conversely, the arc power is decreased significantly, or the input flow of CFC-12 is increased, the CFC-13 concentration at the end of the tube increases to above the level specified by the Montreal Protocol, which corresponds to a mass fraction of just under 10^{-4}.

In order to have confidence in the predictions of a numerical model, it is necessary to validate the results against experiment.

Species	Experiment	Model	
		Original	Adjusted*
CF_2Cl_2	< 0.1 ppm	< 1 ppb	< 1 ppb
CF_3Cl	50 ppm	16.4 ppm	36.8 ppm
CF_4	4-5%	1.21%	2.72%
CO_2	1%	5.65%	12.7%
CO	< 10 ppm	<1 ppb	< 1 ppb

* To facilitate comparison with the experimental data, these calculated values have been corrected for the dissolution of some gases in the scrubber liquid, by multiplication by the ration of the total gas flow to the gas flow expected to pass through the scrubber, which is 2.25. The gas concentrations predicted by the model were used to determine this ratio.

Table 2. Measured and calulated species in the exhaust gas.

Two procedures have been carried out with the model described here. The first is a comparison with the measured concentrations of species exiting the PLASCON device. Table 2 shows a comparison of the predictions of the model with the experimentally measured concentrations. Note that since it was not possible to separate oxygen from argon in the gas chromatograph column used for the measurements presented here, no data are presented for the concentrations of these gases. The experimental parameters were 16 kW arc power, 42 L min^{-1} argon flow, and injection of 40 L min^{-1} CFC-12 mixed with 45 L min^{-1} O_2, which are similar to the parameters used in the model. The measured concentrations are typical, but it should be noted that significant variations from run to run occur. Encouraging agreement with the predictions of the model is found when the measured values are adjusted to take into account the dissolution of many of the output gases in the scrubber. It is correctly predicted that the amount of CF_2Cl_2 remaining will be below detectable levels. CF_3Cl and CF_4 production are predicted to within a factor of two of the measured values. It should be noted that we would expect much of the CO_2 in the output gas to be dissolved in the scrubber liquid, so it is not surprising that the measured mole fraction is smaller than that predicted by the model. With a more efficient scrubber, as is used on the industrial scale 150 kW PLASCON plant, the CO_2 concentration in the exhaust gas is further reduced.

The other validation procedure that was undertaken was measurement of the temperature distribution within the reaction tube using a laser-scattering technique. The method chosen was a combined Rayleigh and Thomson scattering technique that has been previously used (Murphy & Farmer

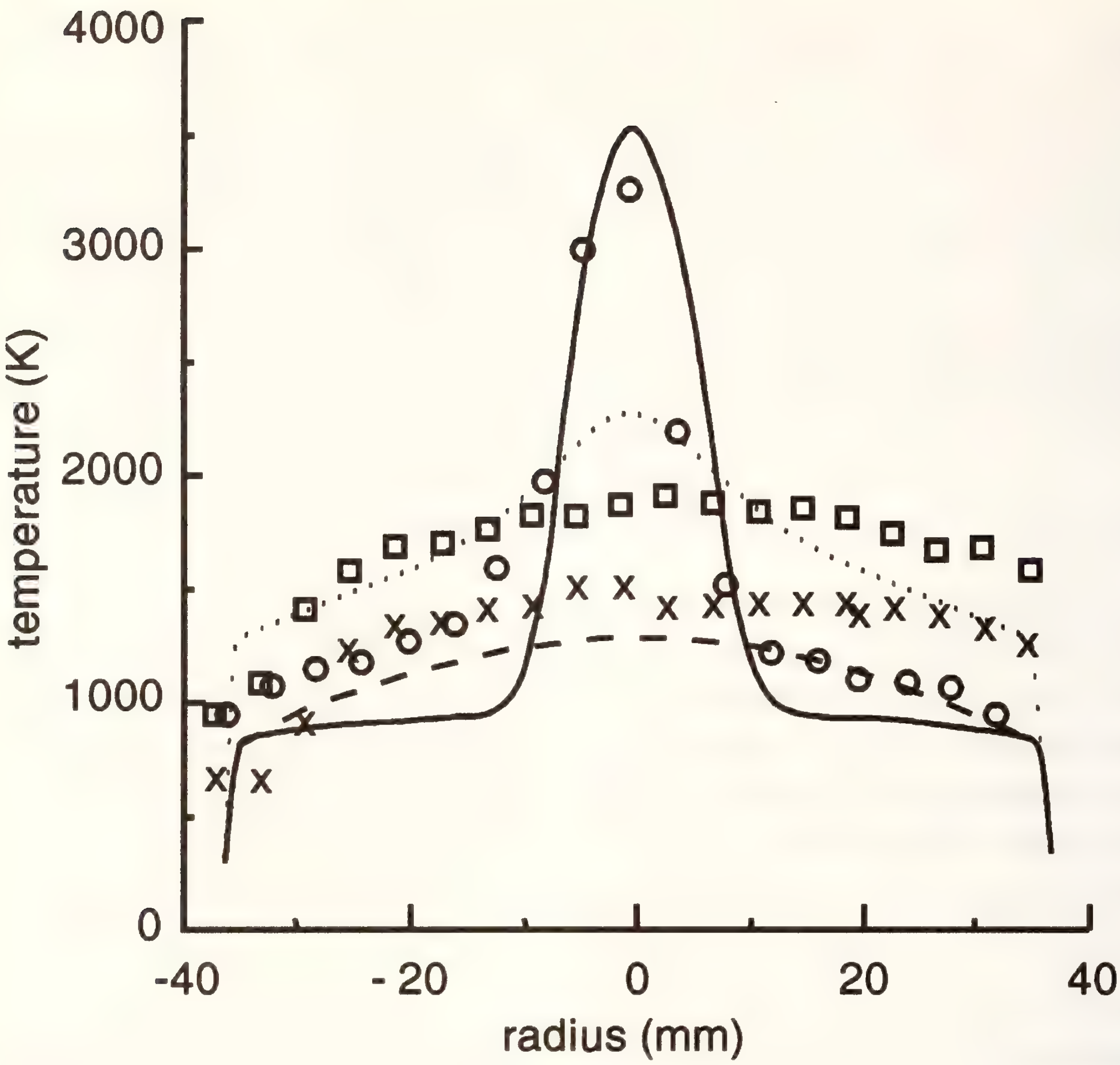


Fig. 4. Radial dependence of temperature at three axial positions in PLASCON for 10 kW arc power, 42 L min^{-1} argon flow, and injection of 80 L min^{-1} oxygen. Lines show result calculated using the numerical model, and symbols show the values measured by laser scattering. —, o: axial position z = 10 mm; . . ., □ : z = 110 mm; - - - , x: z = 410 mm.

1992; Murphy, Farmer & Haidar 1992; Murphy 1994) to measure temperature in free-burning arcs. A scattering chamber was designed to allow optical access to the reaction tube while confining the hot gases inside the tube. Because the technique requires that all species present have similar Rayleigh-scattering cross sections, it was necessary to perform measurements for argon-only operation of PLASCON, or, since oxygen molecules and argon atoms have very similar Rayleigh-scattering cross-sections, for injection of oxygen into an argon plasma jet. The numerical model was run for these conditions of operation in order to provide a valid comparison.

Typical results are shown in Fig. 4 for injection of oxygen into an argon plasma. Fair agreement was found between the measurements and the predictions of the model, although the model predicts more peaked radial temperature profiles than are measured. The higher measured temperatures near the tube wall are expected, since the scattering chamber contained slots in the walls to allow optical access to the full diameter of the tube, allowing the temperature at the tube radius (38.5 mm) to be

significantly greater than the 300 K predicted by the model.

The validation procedures described have given a reasonable level of confidence in the predictions of the model. The model has thus far proved valuable in increasing the level of understanding of the physical and chemical processes occurring in PLASCON, in particular the conversion of CFC-12 to CFC-13. The other main potential use of the model is as a predictive tool, for example to estimate the influence on the exhaust gas composition of changes in reaction tube geometry, flow rates and other parameters. Because reaction rates depend sensitively on temperature, and also because of the significant uncertainties in many of the reaction rate data used, it is unlikely that exact values of the output gas composition will be obtained. Nevertheless, it should be possible to predict the influence on this composition of changes in PLASCON parameters.

CONCLUSIONS

Thermal plasmas have been applied to a wide range of industrial processes. A recent, but rapidly growing, application is to the destruction of hazardous chemicals and other wastes. The Australian-developed PLASCON process has been successfully applied to the destruction of ozone-depleting substances. Both experimental trials and a combined electromagnetic, fluid dynamic and chemical kinetic model show that significant conversion of the input CFC to CFC-13 occurs in PLASCON, and that CFC-13 is typically the ozone-depleting substance that is present in the highest concentration in the exhaust gas. The model has been used to determine in which part of the process the chemical reactions that lead to the formation of CFC-13 occur. Temperatures in the reaction tube and the exhaust gas composition predicted by the model have been confirmed by experiment.

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The author is grateful to Dr T. McAllister of CSIRO Division of Manufacturing Technology for providing the chemical kinetic scheme used in the numerical model described here and for many useful discussions. He also thanks Mr R. E. Bentley, Dr A. J. D. Farmer and Dr J. Haidar of CSIRO Telecommunications and Industrial Physics, with whom he collaborated on the laser-scattering measurements. The contributions of Dr Farmer, Ms E. C. Horrigan and Dr L. M. Besley of CSIRO Telecommunications and Industrial Physics and Dr A. R. Dayal, Dr. R. T. Deam, Mr R. J. Western and Mr A. E. Munday of CSIRO Division of Manufacturing Technology, who are responsible for the results of the laboratory tests of destruction, are also acknowledged. The financial support of SRL Plasma for the PLASCON research is gratefully acknowledged.

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Theses Abstracts

THE FEASIBILITY OF USING MOLE DRAINAGE TO CONTROL WATERLOGGING IN IRRIGATED AGRICULTURE

E.W. CHRISTEN

Abstract of a Thesis Submitted for the Degree of Doctor of Philosophy at Cranfield University, England September 1994.

The Murrumbidgee Irrigation Area (MIA) in New South Wales has extensive shallow watertables, <2m deep, and poorly structured heavy clay soils, leading to soil waterlogging and salinisation. This study investigated the feasibility of using mole drainage to control waterlogging in irrigated agriculture. The standard moling technique used in the United Kingdom in rainfed agriculture was adapted to the flood irrigated conditions of the MIA.

Experiments were carried out on three heavy clay soils, representative of the area and with a range of inherent structural stabilities in water. Preliminary experiments identified mole channel failure mechanisms similar to those already described in the United Kingdom. Having identified these mechanisms steps were taken to improve mole stability.

Two relatively stable soils and one highly swelling\dispersive soil were chosen. Experiments to improve mole stability were carried out under furrow irrigation, flood irrigation of bays and sprinkler irrigation. These experiments consisted of groups of 30-50 moles, each 25-50 m long. Four main experimental sites were monitored for between 6 and 22 months.

In the stable soils the mole failure mechanism was by roof/expander failure. Using a mole plough with smaller geometry than the standard United Kingdom design resulted in acceptably stable mole channels in these soils. The use of an angled mole leg was found to have potential for increasing mole stability but further development of this equipment is required for reliable mole formation.

In the unstable soil the mole failure mechanism was by unconfined soil swelling. To control this, gypsum was used above the mole channel to improve the inherent soil stability. The use of sulphuric acid and calcium chloride sprayed onto the mole channel walls proved unsuccessful. A mole filler of rice hulls was found to be effective in preventing soil swelling into the mole channel.

For stable mole formation adequate confining stresses and uniformly plastic soil conditions at moling depth were required. Post rice harvest was found to be ideal. Methods of achieving suitable conditions at other periods in the farming calendar were identified.

Mole discharge measurements revealed that water loss through mole drains during irrigations was high. Thus there was a requirement to prevent this water loss whilst still achieving waterlogging control.

To prevent water loss during irrigations attempts were made to throttle the connection between the soil surface and mole channel.

These were found to be largely unsuccessful. By blocking the mole channels during irrigation, discharge was prevented and mole condition was not impaired more greatly than allowing moles to discharge freely.

Mole drainage was found to control waterlogging but crop yield increases were only around 10%. To achieve the optimum benefit from mole drainage secondary soil loosening to increase soil porosity is required.

The salinity of mole drain discharge water was measured. This revealed that mole leached salts and that the leaching was more efficient under rainfall or sprinkler irrigation than flood irrigation. The mole drain discharge water was usually of suitable quality for refuse on farm.

The research showed that there is the potential for using mole drainage to control waterlogging and salinity in irrigated agriculture, at a lower cost than with pipe drains. Methods for incorporating mole drainage into the farming system and landscape of the MIA are proposed.

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Theses Abstracts

DYING IN PRISON: A STUDY OF DEATHS IN CORRECTIONAL CUSTODY IN SOUTH AUSTRALIA 1980-1993

M. J. DAWES

Abstract of a Thesis Submitted for the Degree of Doctor of Philosophy,
Flinders University, South Australia 1997.

This thesis examines the 38 deaths by accident, homicide, natural causes and suicide of Aboriginal and white prisoners which occurred in the South Australian prison system from 1 January 1980 to the 31 March 1993. The pattern of deaths in SA is compared with the pattern of deaths found nationally by the Royal Commission Into Aboriginal Deaths in Custody (RCIADIC) and the differences between the SA and national populations are discussed. Other variables which were not included in the RCIADIC are considered in this thesis such as the security rating of the prison, the location of death, time of death, month of the year and season.

A case control study was designed to identify any combinations of personal and social differences between the 37 male prisoners who died and a control group of 195 prisoners matched for gender and date of admission. Most of the studies into deaths in custody fail to compare their findings to a properly constructed control group and so the question remains as to how many of the surviving prisoners exhibited the same characteristics and were exposed to the same environment as those who died. The theoretical grounding for the case control study is that deaths in custody occur because of the interaction between personal factors (those characteristics which the prisoner imports to the prison) and situational factors causing distress which occur while in prison. A review of the literature shows that much of the research work to date has been to search for a statistically based profile of the 'at risk prisoner', but this thesis suggests that attempting to identify vulnerability based on the interaction between personal and situational factors is a more useful approach. The case control study showed that there are statistically significant differences between those who died and the control group in terms of age, place of birth, marital status (with prisoners who were separated or divorced being more likely to die in custody), number of times in custody, time served, seriousness of offence including use of violence, physical trauma, significant illness, psychiatric illness, taking medication while in custody and when security measures were taken to protect, isolate or punish.

An analysis of the coronial verdicts in 36 of the 38 deaths was undertaken to determine the extent to which deprivational factors substantially contributed to the individual deaths.

The findings of the thesis are discussed in the context of the literature and the value of the findings in assisting those who care for prisoners considered. Finally, preventive strategies are discussed and social work interventions which might identify and assist vulnerable prisoners and their families at critical times are considered.

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THE INTERFACE BETWEEN SYNTAX AND DISCOURSE IN KORAFE, A PAPUAN LANGUAGE OF PAPUA NEW GUINEA.

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Abstract of a Thesis Submitted for the Degree of Doctor of Philosophy at Cranfield University, England, September 1994.

This dissertation focuses on the structure and function of three types of complex constructions which are central to Korafe discourse: (1) serial verb constructions (SVCs), (2) switch reference constructions (SRCs), and (3) co-ranking constructions or sentences (CRSs).

Each of the complex construction types has as obligatory constituents trio or more clauses or verbs. SVCs and SRCs are 'chaining' constructions, which terminate with a verb, more finitely inflected than the preceding verbal constituents i.e. verb stems in SVCs and medial verb forms in SRCs. Syntactic constraints masked on or implicit in chaining structures enable the speaker to monitor subject reference from verb to verb without using very many overt noun phrases. The order of the verbs in these chains is non-reversible and mirrors the order of the events they represent in the real world. This makes them choice vehicles for conveying the foregrounded story line in narratives, legends, and procedures. Utilising verbs without their standard arguments to a) represent familiar events (e.g. *ghambudo* 'dig' for 'dig a hole', *jedo govedo* 'chop plant' for 'making a garden') and b) mark shifts in venue or temporal seeing *(aira buvudo* 'he went and arrived', *ravara atetiri* 'they slept and it [day] dawned') enables the speaker to concentrate on the specifics of the story in question, use noun phrases to highlight dominant and/or prominent participants and props.

In CRSs, all the constituents terminate with verbs of the same rank, namely final verbs, or in topic-comment constructions, predicate complements. CRSs combine clauses, SRCs, and/or other co-ranking sentences by juxtaposing or conjoining them. CRSs supply background information in discourses that primarily present events in iconic order. They are also extensively used in more thematically oriented discourses, such as encyclopaedic descriptions, explanations, and hortatory speeches.

SRCs and CRSs may be segmented into information chunks that are thematically unified. These thematic clause chain units (TCCUs) are defined by formal and semantic criteria. They range from one to nine words, comprising up to five clauses in an SRC and averaging between one to four seconds in length. They are uttered as a basically pause-free unit.

Other features of the language relevant to the account of these complex constructions are also described.

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Theses Abstracts

THE EARLY DEVELOPMENT OF CLINICAL DIALYSIS: THE IMPORTANCE OF SYMBOLISM IN SUCCESSFUL SCIENTIFIC ENDEAVOURS.

C.R.P. GEORGE

Abstract of Thesis Submitted for the Degree of Master of Science at the University of Sydney

This thesis presents an account of the series of experiments performed into dialysis by Thomas Graham in 1861; by his immediate successors; by Emil Abderhalden and Fritz Pregl; by the Baltimore group of John Jacob Abel and his Collaborators (1913-15); and by others who were more peripherally involved. Its primary purpose is to demonstrate the roles that each of these investigators played in the development of clinical dialysis. Its secondary purpose is to propose a novel theory of success in the scientific endeavour, and to use dialysis as a case study with which to test this.

An account is presented of Graham's experiments, his development of an idea, and his invention of the word *dialysis* to describe the observations and idea. He recognised that urea - an important uraemic toxin - was dialysable. He established his reputation by a forceful application of observation, conceptualisation, and symbolism to the topics that he investigated.

Several minor figures followed Graham, but were soon forgotten. Then Abderhalden attempted to use dialysis in a test for pregnancy, but based *the Abderhalden reaction* on false assumptions. His observations and his ideation were flawed. Although he developed a symbolic name for his test, it did not work. He lapsed into obscurity. Pregl, however, applied dialysis successfully to *microanalysis* of chemicals. His observations, ideas and symbolism succeeded; he won a Nobel Prize for Chemistry and his procedures entered all modern biochemical laboratories.

Abel was far more complex. His personal laboratory notebooks are held in the Johns Hopkins Hospital archives. A reworking of these is presented and demonstrates that his private aims differed from his public ones. His assistants' intentions also were hardly those of idealistic scientists. His observations were flawed and his ideas confused, but his reputation survived his own misinterpretations because of adulation of his work by a gullible lay and medical press. Perhaps his misinterpretations were fortuitous, but probably they were not. Certainly, they implied clinical applications far beyond those justifiable by the documented records claims which Abel never really denied, and which his assistant Rowntree, actively encouraged. Driven by the publicity, Abel embarked upon a hopeless - and apparently lethal - experiment on a sick young woman. Uninformed about that disaster, community acceptance - the factor crucial to the judgement of experiments as 'successful' - remained uncritically positive. It idolised Abel (in truth, a some-

what hapless scientist) as a brilliant physician and the inventor of *the artificial kidney machine*. His symbolism survived just long enough to enable his successors to link their more reliable observations and ideas with it, to develop these to clinical fruition, and thereby to secure for Abel his place as an apostle of science.

The secondary purpose of this thesis is to propose a *trinitarian* theory of scientific success. Observations, ideas, and symbols are three co-existent and necessary components of a successful scientific enterprise. None is sufficient without both of the others. Observations alone are empty. An astute observer can weld observations together into ideas, but unanchored ideas will float away. Society is most likely to judge an observer as a successful contributor to science if that observer creates appropriate symbols (usually unique words or phrases), with which to fix accurate observations and good ideas - to epitomise their meaning to the public.

An interesting application of this theory relates to the public relations implications of unsubstantiated symbolism. Reluctance to admit this can then so readily promote false observational claims and the temptation of scientific fraud.

Whilst a single case study can at best merely support a hypothesis - it will never prove it - the evidence from dialysis dovetails with the present contentions. Hence their validity may be worth testing against other cases.

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Theses Abstracts

CHEMICAL RELATIONSHIPS IN WATERS AND SEDIMENTS OF SOME URBAN STREAMS, WITH PARTICULAR REFERENCE TO HEAVY METALS AND PHOSPHORUS.

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Abstract of Thesis Submitted for the Degree of Doctor of Philosophy
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This thesis describes two studies of the chemistry of freshwater streams in the Sydney basin.

The first was a survey of 86 waterways, sampled under low flow conditions. Samples were generally low in salinity, soft, of poor buffering capacity and dominated by sodium and chloride. Co-dominance by calcium, magnesium and (bi-)carbonate occurred in a number of particular cases. Multivariate analyses indicated three groups, separated primarily by levels of dissolved nutrients, trace metals, turbidity and colour. Groupings were associated strongly with the type of catchment development. Streams in areas relatively unaffected by human influence had notable uniformity in chemistry, while those from developed catchments were varied. Heavy metal contamination was relatively low, although a few of the samples displayed inordinately large levels of one or more metals. In such cases the more extreme measurements of phosphorus and nitrogen were also seen. These findings were consistent with occasional or localised elevation of contaminant levels.

The second study involved monitoring of three Hawkesbury Sandstone streams. Sampling of surface waters, interstitial waters and sediments was performed at irregular intervals over a two year period at three stations within each site. The streams predominantly existed under low flow conditions and showed similar major ion chemistries to the majority of the survey samples. Levels of calcium and total carbonate, plus heavy metals and nutrients were generally higher in the urbanised creeks, compared to the reference stream. During a heavy storm, high levels of nutrients, suspended solids and colour were detected in all surface waters at peak-flow, as well as alkaline pH, oxidising redox, and reduced conductivity, alkalinity and hardness.

The sandy sediments were characterised by very low levels of organic matter and cation exchange capacity. Sequential extractions identified that the sums of secondary phase lead, zinc and copper were over nine, four and two times that of the corresponding residual, respectively. Greatest proportions of zinc and lead were associated with coatings of iron and manganese oxides, or coarse waste particles. Copper was preferentially associated with organic matter. Concentration gradients between interstitial and surface waters were rare and release of sedimentary constituents should occur rapidly from the upper-most particulates.

Poor water and sediment qualities were often observed in the urban sites. Poor water quality was also seen on occasion in the

reference stream. However, since poor sediment quality was not detected at those times and interstitial waters for all sites displayed high within-site variability, surface waters were considered the most reliable short-term indicator of condition for Hawkesbury Sandstone streams. Multidimensional scaling showed that all streams had distinct water and sediment chemistries. High levels of temporal and spatial variability were apparent within the urbanised sites - particularly in interstitial waters - mostly due to concentrations of heavy metals, phosphorus and suspended solids. Seasonal differences were detected, but only in terms of the level of variability between summer and winter samples.

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Theses Abstracts

SOIL ACIDIFICATION IN THE HUNTER VALLEY

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Abstract of Thesis Submitted for the Degree of Master of Science
Charles Stuart University, Wagga Wagga NSW,1996

Soil acidification due to agriculture is a widespread and significant problem in Australia. Soil acidification from fossil fuel use and deposition of resulting acids onto the landscape may also be important in some areas, but has received little study in Australia. The latter phenomenon is known colloquially as acid rain. This thesis examines these problems in the Hunter Valley, an important agricultural region with two large coal-fired power stations.

Acid deposition from the power stations is estimated from rainwater chemistry and modelled atmospheric SO_2 concentrations. Acid production from agriculture is estimated from agricultural land suitability and climatic information. Soils collected from 51 sites are analysed. Four soil classes were defined, differentiated by their parent materials; basalt (I), shale, siltstone and felsic igneous rocks (II), sandstone (III), and alluvium (usually basaltic, IV). Surface soils at 7 of the 51 sites are already strongly acidic (pH, 1:5 soil:O.O1 $M CaCl_2$, < 4.5), and have high concentrations of exchangeable aluminium ($A1^{3+}$).

pH buffer capacity () was measured in all 51 surface soils (0-10 cm), and in 59 samples from various depths between 10 and 100 em. Soil pH buffer capacity (0-10 em) between pH 4.5 and pH 6.5 ranged from 7 to 50 mmol H^+/kg/pH, and this is highly correlated with organic carbon concentration (OC, %). Buffer capacity (pH 4.5 to 6.5) per unit OC is greater at depth, as expected for more humified organic matter. Weak organic acids are therefore important substances buffering pH in these soils.

The dissolution of basic soil minerals increases soil pH. This was studied by incubating several soils with acid at 60^0C to enhance otherwise slow dissolution. Basic non-carbonate minerals dissolved in 1 basaltic soil, and manganese oxides dissolved in all of the soils. Soil pH was also affected during incubation by the oxidation of organic C and mineralisation of organic N.

Soils sensitivity to added acids was calculated from the quantity of acid (kmol H^+/ha/year) necessary to reduce the surface pH to a target value (4. 5) in 50 years. This indicator is high in classes I and IV, variable but mostly low in II, and very low in class III, where the mean is less than 0.2 kmol H^+/ha/year. The most acid-sensitive soil types (II and III) occur in 366,000 and 168,000 ha of the study area (656,000 ha) respectively.

Agriculture poses a very high risk to approximately 10,000 ha of soil types II and III, and another 156,000 hectares is at a lower risk. Acid deposition also poses a substantial risk to sensitive soils. A small area of type III soils and a large area of type II soils are affected by high rates of acid deposition (> 0.4 kmol H^+/ha, 3,000 and 91,000 ha, respec-

tively). The exact risk to type II soils is difficult to determine because basic mineral dissolution may buffer the pH in these soils. Better understanding of mineral dissolution in soil types II and III is needed to accurately assess their sensitivity to acids.

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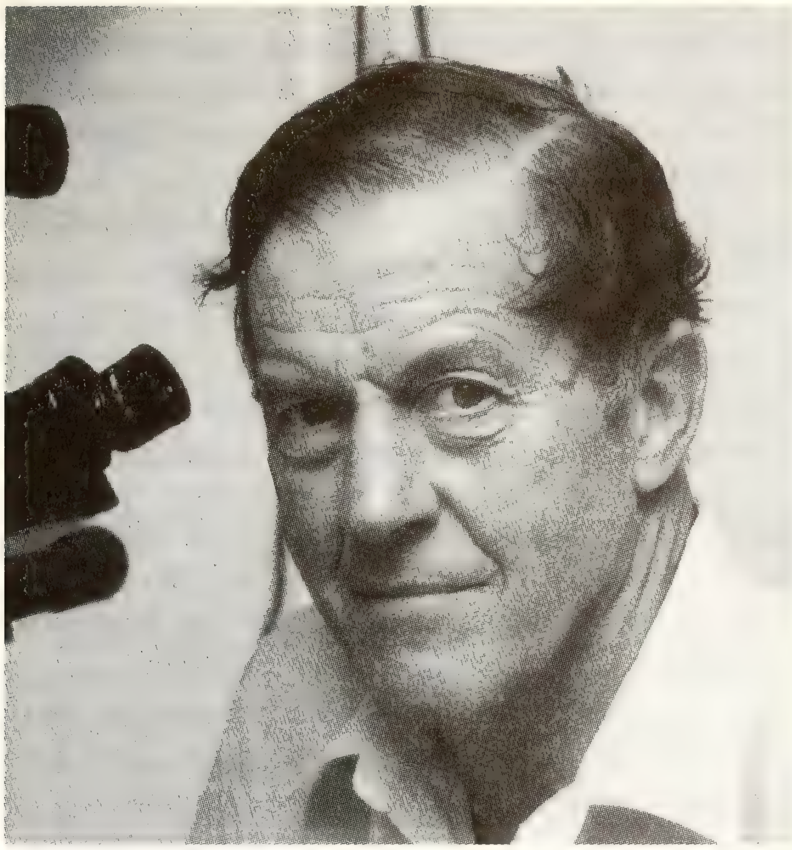
(Manuscript received 24.7.97)

Biographical Memoirs



JOHN ANTHONY MILBURN
1936-1997

Professor John Anthony Milbum died tragically in a light airplane crash on 9th June 1997 in Armidale, at the peak of his career.

John Milburn was born on 7th August 1936 in Carlisle, Cumbria, U.K.. He received his education at Carlisle Grammar School, Carlisle, U.K.(1947-1955), and then went on to study at the University of Newcastle-upon-Tyne (1955-1958) and the University of Aberdeen (1961-1964). He was awarded the B.Sc. (Hons., Botany), 2.1 at the University of Newcastle in 1958, and the Ph.D. in plant physiology at the University of Aberdeen in 1964. In 1986 he was elected Pellow of the Institute of Biology (London).

From 1958 to 1960, he held the position of Agronomist (Sugar Cane) with Dr. H.E. Evans, Bookers Sugar Estates Ltd., Guyana, and from 1964 to 1975 that of Lecturer, and from 1975 to 1980 that of Senior Lecturer at the University of Glasgow. In 1980 he was appointed Reader at this University. He took up the Chair of Botany at the University of New England in January 1981. From 1981 to 1988 he was Head of the Department of Botany, UNE, and from 1982 to 1984, he also served as Dean of the Faculty of Science. From 1990 to 1993 he was the external examiner for Botany at the University of Hong Kong. He won several fellowships. From October to December 1972 he was an Overseas Visiting Fellow of the British Council, from 1973-74 a Fulbright-Hays Scholar, and from 1973-74 a Charles Bullard Research Fellow of Harvard University.

From an early age he was interested in the flow of water in plants. He played a major role in the elucidation of xylem and phloem transport physiology, in particular the detection of cavitation by acoustic detection. His research interests were, however, very broad and included such areas as the history of plant sciences, ultrastructural studies on moss and fern sporangia, physiology of latex flow, life of cut flowers, and algal flora in Annidale waters.

John Milburn has published several books and book chapters of international standing and close to 100 research publications. His book 'Water Flow in Plants', published by Longman in 1979, is widely used as a text. He had such a profound impact on plant physiology that every single current textbook on the subject in the world, and indeed many general botany texts, list his publications. The Australian Society of Plant Physiologists invited him to be a keynote speaker at its forthcoming meeting in Melbourne. He is considered as the father of the idea of cavitation and embolism and I am told that there is now a specialist Society of some 150 people working in this area in the free world.

He presented many oral papers and seminars to learned societies and university departments in Europe, America and Asia including addresses to the British Association (Leeds 1967) and to the International Botanical Congresses in Leningrad (1978) and Sydney (1981). He organised and chaired sessions in plant physiology at the congresses.

At Glasgow John Milburn supervised six research students, and at UNE 13 including two who are now writing up their theses.

John was a member of the Society for Experimental Biology, the Australian Society of Plant Physiology, the Australian Society for Biophysics, the Australian Academy of Science (1985-1988), a Member of the National Committee for Plant Sciences (1985-1988), the International Society of Plant Physiologists, a Fellow of the Institute of Biology, and a Member of the New York Academy of Science and the American Association of Science.

John Milburn joined the Royal Society of New South Wales in 1986 as a full member. He was a keen supporter of the Armidale Branch of the Society and arranged several outstanding evening talks.

John is survived by his wife, Anita, sons Dirk and Erik, and daughter Hazel.

K.R.

SIR JOHN PROUD
1907-1997

On 7 October 1997, aged 90, JOHN SEYMOUR PROUD passsed to the Great Beyond.

Knight Bachelor, Bachelor of Engineering, Honorary Doctor of Engineering and Fellow of the Senate from 1974 to 1983 in the University of Sydney, Honorary Doctor of Laws in the Australian National University; Sir John Proud was a Fellow of the Institution of Mining and Metallurgy, Fellow of the Australasian Institute of Mining and Metallurgy; Fellow of the Institute of Marketing Management, Fellow of the Institution of Engineers Australia, and Life Member of the Royal Society of NSW.

We celebrate his adventurous and productive life. We knew him for his contributions to mining and his promotion of excellence in advanced learning and research. He was instrumental in establishing Foundations in Electrical, Civil and Mining Engineering as well as the privately-funded environmental "Earthwatch Australia". Also a Trustee of the Australian Museum from 1971 to 1977, he was the Founder and Chairman of Trustees of the Lizard Island Reef Research Foundation from 1978-1987. Successful as a Company Director and Chairman, Consultant and Benefactor, the sincerity and trust between John and his team of first class colleagues was a feature of that success.

From school John entered his Family's business briefly, but without enthusiasm. He studied to matriculate, and in due course graduated as a Bachelor of Engineering in Mining and Metallurgy at the University of Sydney.

Early in 1937 he spent three weeks in New Guinea and acquired malaria. He joined the small Stinson Airliner's daily flight from Brisbane to Sydney, on 19 February 1937, six months before his 30th birthday.

Approaching the precipitous, jungle-covered McPherson Ranges, the plane met an unreported cyclone with headwinds of about

80 mph. It crashed in the rainforest and burst into flames. Proud, Binstead and Westray survived. But neither radio nor meals were carried in those days. The fittest survivor was Westray, who went for help, though his hands were badly burned and he was hungry. John Proud, immobile with his leg broken and bone protruding, was settled alongside the burnt wreckage. Binstead knew that John would die if water were not brought to him daily from the gorge. Each trip took hours of agonised crawling with hands like raw meat. For nine days both were without shelter or food or warmth in the rainforest. John scratched a daily diary on a fragment of torn aircraft metal....

The failed air search was called off. But the mountain man Bernard O'Rielly listened to that *still small voice*. The plane must be out there somewhere, not in the sea off Palm Beach, as newspapers said. A week after the crash, he began to search and miraculously found the wreck, though it was invisible from 20 feet away. Realising that John might not last another day without help, Bernard O'Rielly gave Proud and Binstead his remaining cooked potato and onion and set out immediately downhill to the south, passing Westray's body propped against a boulder. O'Rielly forced himself to take risks in a race against approaching darkness. Exhausted, he reached the first open ground in the valley at nightfall. Picked up by a farmer, he was driven nine miles to a telephone to give his message to the world.

Grace Silcock spent all night on that phone, organising the hundred men who set out next morning with sharpened axes to cut a track up the mountain through the dense jungle. The rest is history, written in *Green Mountains*, O'Rielly's book, and seen in the Video made fifty years later in 1987 by John Schindler.

John Proud owed much to many; not least to Binstead for the life-giving daily water ration; and to the swarming blowflies which ate the rotting green flesh of his leg wound, thus avoiding gangrene infection. It was a method soon to be used widely in the jungles of our generation's Pacific War.

John Proud's visit to me in the SOLOMON ISLANDS late in 1950 influenced my life and began a decade of mineral exploration for nickel, cobalt and chromite, at no expense to our Geological Survey. I must add that John had another close shave when he nearly trod on a very mature crocodile one morning

John succeeded Sid Sangster of PEKO MINES and with George Lean's help soon merged that company with NEWCASTLE WALLSEND COAL. Other mines followed: Mount Morgan, King Island Scheelite, Rutile Zircon Mines and other major beach-sands properties. John became Chairman of PEKO-WALLSEND LTD in 1960 until 1978, when George Lean took over.

The need for success in mineral search demanded the special role of Geopeko, which became itself a story of successful discoveries under Dr John Elliston.

The discovery of Ranger Uranium mine was blighted by the hostility of bureaucracies and a succession of governments, one of which tried confiscation. The mess cost Australians untold jobs and billions of dollars. The mine was shared by EZ. The story from the inside has now been told by Keith Alder in his book, *Australia's Uranium Opportunities: How her Scientists and Engineers Tried to Bring Her into the Nuclear Age but were Stymied by Politics*. It was strongly encouraged by Sir John Proud so that the story could be known to Australians from whom it has been withheld.

Sir John was a director of CSR from 1974 to 1979, Chairman of Oil Search Ltd. from 1978 to 1982; Chairman of the Electrical Equipment Ltd Group 1978 -1982, and Chairman of Oil Company Australia N.L.

John's rapid rise in business began in 1960.. He was Knighted in 1978.

This short summary would be incomplete without acknowledging the role of Laurine, Lady Proud, who supported him so fully in his varied activities since their marriage in 1964.

J.C.G.

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